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# Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-66

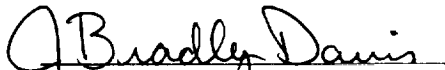
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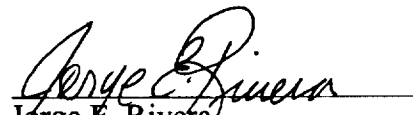
**DEBRIS/ICE/TPS ASSESSMENT  
AND  
INTEGRATED PHOTOGRAPHIC ANALYSIS  
OF  
SHUTTLE MISSION STS-66**


**3 November 1994**

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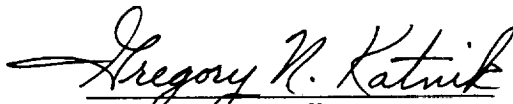
  
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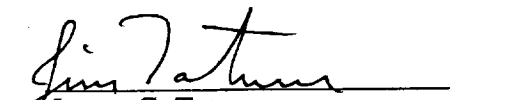
  
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## **FOREWORD**

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.



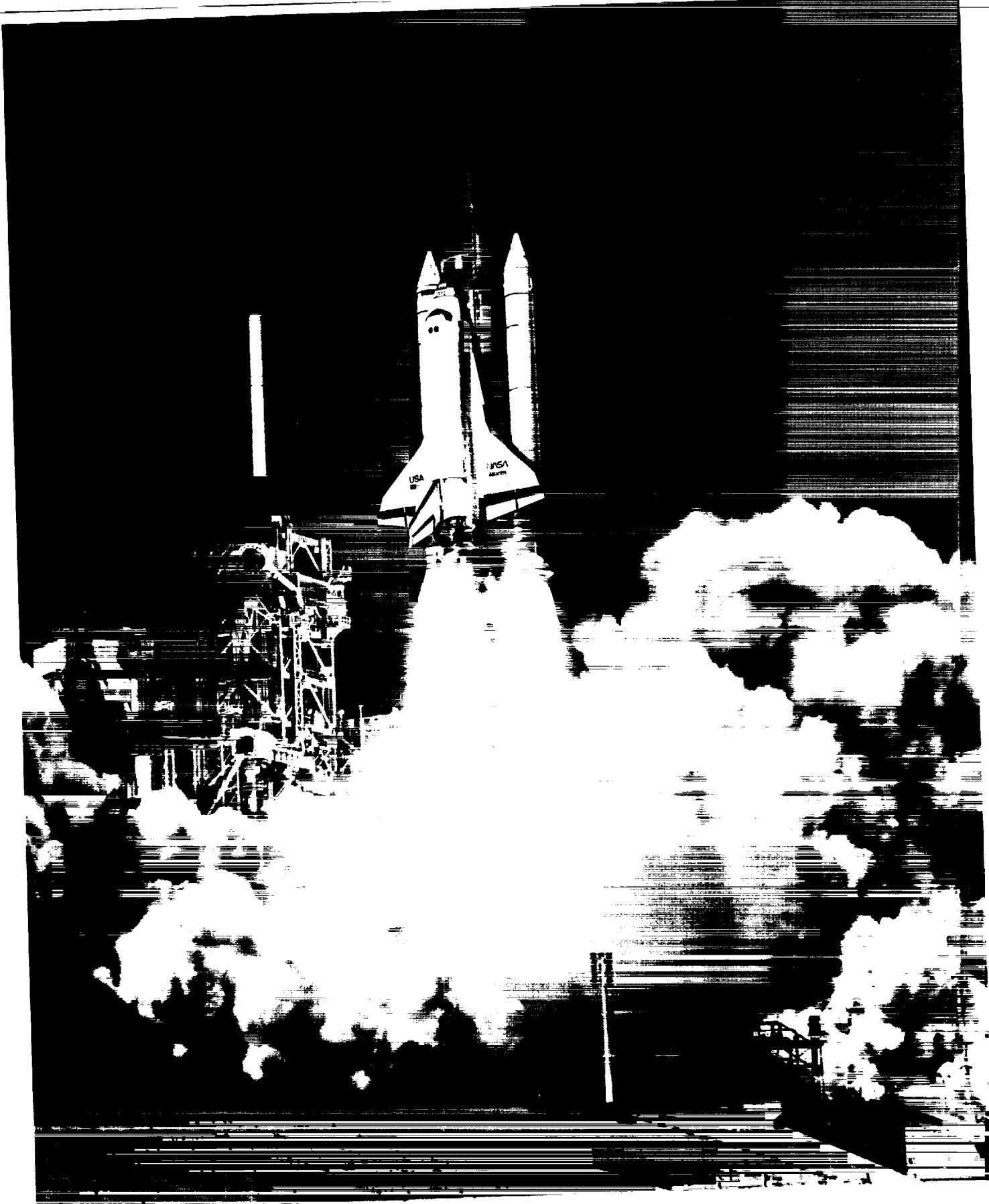


Photo 1 : Launch of Shuttle Mission STS-66



## 1.0 SUMMARY

A pre-launch debris inspection of the pad and Shuttle vehicle was performed on 2 November 1994. The detailed walkdown of Launch Pad 39B and MLP-3 also included the primary flight elements OV-104 Atlantis (13th flight), ET-67 (LWT 60), and BI-069 SRB's. There were no vehicle anomalies. Four facility debris items were documented for resolution prior to ET cryoload.

The vehicle was cryoloaded on 3 November 1994. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Due to the ambient weather conditions at this time of year, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

After the 11:59:43 a.m. (local) launch on 3 November 1994, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. There was no visual indication of a stud hang-up on any of the south holddown posts. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 97 films and videos were analyzed as part of the post launch data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. Dark carbon-type residue from the GOX seals, which had appeared on the STS-64 and STS-68 ET nosecones, was not present on the STS-66 ET nosecone after the GOX vent hood was retracted. A black tile fragment, estimated to be 6 inches by 2 inches by 1 inch thick in size, fell aft near the body flap at GMT 16:59:40.375. The tile fragment originated at the body flap hinge line area (+Z side) near the SSME #2 base mounted heat shield and was shaken loose during SSME startup.

On-orbit photography of the External Tank after separation from the Orbiter revealed two TPS divots on the LO2 tank at or near the LO2 pressurization line ramps. Three stringer head divots were observed on the intertank acreage: one 14-inch divot just forward of the -Y bipod spindle housing closeout; one 17-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods; and one 24-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods. (This type of divot had been the subject of a previous IFA. Manufacturing procedures at the factory were modified, effective on ET-74, to reduce the potential for TPS damage during intertank assembly). The lightning contact strip across the forward part of the LO2 ET/ORB umbilical was missing and observed drifting near the crossbeam.

Video footage of the ET after separation showed venting of residual gases from the ET/ORB umbilicals. Pieces of frozen hydrogen originated from the LH2 ET/ORB umbilical and drifted away from the tank. This activity was expected and had been previously documented on the STS-45, STS-53, and STS-68 missions.

Video taken from the RMS wrist camera showed liquid expelled from the supply water dump nozzle on the port side of the Orbiter near the crew hatch. The video also revealed the water had frozen, adhered to the port payload bay door, and formed an icicle estimated to be at least 4 feet in length. This condition was the subject of an IFA. No camera coverage of payload bay door closing was available to determine the amount of ice still attached to the outer surface of the door. Some of this ice, which broke off and fell aft during re-entry, is believed to be the cause of tile damage on the RH OMS pod leading edge and the vertical stabilizer. Post landing inspections and film review showed ice still adhering to the left payload bay door after rollout and wheel stop.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. The RH frustum was missing no TPS but had 50 debonds over fasteners and 2 debonds over acreage. The LH frustum was missing no TPS but had 39 MSA-2 debonds over fasteners. Since the number of debonds was greater than the frustum history average of 25 debonds per frustum, a representative set of the MSA-2 debonds were analyzed by MSFC under an IFA for possible material or processing anomalies. The problem was traced to an MSA-2 spray pump problem. Otherwise, both recovered SRB's were in good condition from a debris standpoint.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing inspection of OV-104 Atlantis was conducted on the runway at Dryden Flight Research Center/Edwards AFB. The Orbiter TPS sustained a total of 148 hits, of which 28 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger were slightly greater than average. The Orbiter lower surface sustained a total of 111 hits, of which 22 had a major dimension of 1-inch or larger. The two largest damage sites on the lower surface were located forward of the LO2 ET/ORB umbilical and measured 7.375 inches by 3.75 inches by 0.5 inches and 5.25 inches by 1.25 inches by 0.25 inches.

The supply water dump ice deposit on the forward section of the left payload bay door, as observed in the on-orbit video downlink, was still attached after landing and measured approximately 8 inches by 4 inches by 2 inches. The largest tile damage sites on the orbiter were located on the top of the RH OMS pod forward facing surface measuring 8 inches by 5 inches by 2 inches and on the leading edge of the right rudder/speed brake panel measuring 12 inches by 4 inches by 2 inches. The damage to these two areas was most likely caused by impacts from supply water dump ice falling aft from the payload bay door.

A 2 inch by 1 inch by 1 inch thick portion of an aft perimeter tile on window #8 was missing and was the subject of an IFA because of a similar occurrence on the previous mission, STS-68.

This was the first use of a refurbished drag chute. All drag chute hardware was recovered and showed no signs of abnormal operation.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from the window protective covers, facility environment, SRB BSM exhaust, Orbiter TPS, RCS thruster paper covers, and paints/primers from various sources. A late sample taken from OV-105 windows after the STS-68 mission provided material that has been identified as RCS nozzle paper cover. The paper visually compared to the red and white checkered 'butcher paper' used on forward RCS nozzles to prevent moisture intrusion. Motion picture cameras previously mounted in the pilot's window on some of the launches early in the program had documented FRCS paper cover impacts on the forward facing windows during ascent. This sampling data further confirms the presence/contact of paper cover material on the windows. These residual sampling data do not indicate a single source of damaging debris as all of the other materials have previously been documented in post-landing sample reports. The residual sample data showed no debris trends when compared to previous mission data.

A total of twelve Post Launch Anomalies, including three In-Flight Anomalies (IFA's), were observed during the STS-66 mission assessment.

## 2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 2 November 1994 at 1130 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC Shuttle Ice/Debris Systems
B. Davis	NASA - KSC Digital Imaging Systems
R. Speece	NASA - KSC Lead, Thermal Protection Systems
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G. Fales	LSOC - SPC ET Mechanical Systems
M. Jaime	LSOC - SPC Lead, ET Mechanical Systems
S. Clarke	Rockwell LSS Systems Integration
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S. Otto	MMMSS- LSS ET Processing
K. Ely	MMMSS- LSS ET Processing
D. Maxwell	LSOC - SPC Safety

### 3.0 LAUNCH

STS-66 was launched at 94:307:16:59:43.004 GMT (11:59:43 a.m. local) on 3 November 1994.

#### 3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on November 2, 1994, from 1230 to 1400 hours. The detailed walkdown of Pad 39B and MLP-3 also included the primary flight elements OV-104 Atlantis (13th flight), ET-67 (LWT 60), and BI-069 SRB's. There were no vehicle anomalies.

Four facility debris items were entered in Appendix K for resolution prior to ET cryoload: 1) construction debris around substation 1032 east of the pad slope; 2) rusted/loose electric outlet, brackets, and conduit on the east pad apron; 3) rusted/loose distribution box on the east apron; and 4) a considerable amount of rust/metal flakes near the loose distribution box. All of these discrepancies were not a debris threat to the vehicle for launch, but could have damaged other pad systems, such as the nearby liquid hydrogen sphere. No specific group has been tasked with responsibility for foreign object debris issues in the areas from the pad slope to the perimeter fence. Pad site managers will meet to resolve this concern.

#### 3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 3 November 1994 from 0800 to 0915 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Due to the ambient weather conditions at this time of year, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

Ambient weather conditions at the time of the inspection were:

	<u>T-3 Hours</u>	<u>T-0 Launch</u>
Wind Speed (knots):	11	09
Wind Direction (degrees):	068	069
Relative Humidity (percent):	67	65
Temperature (degrees F):	74	76
Dew Point (degrees F):	63	64

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to scan the vehicle for unusual temperature gradients, particularly those areas not visible from remote fixed scanners, and to obtain a random sampling of vehicle surface temperature measurements to thermally characterize the vehicle.

#### 3.3 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster paper covers were intact and dry. Less than usual ice/frost accumulations were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

### 3.4 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the fixed STI radiometers ranged from 72-75 degrees F. In comparison, temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 72-77 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by MTI was 76 degrees F, which was within the required range of 44-86 degrees F.

### 3.5 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank. There were no TPS anomalies.

The intertank acreage exhibited no TPS anomalies. Typical ice/frost accumulation, but no unusual vapor, was present on the ET umbilical carrier plate.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost accumulations, were present on the acreage.

There were no anomalies on the bipod jack pad closeouts. A crack, 4 inches long by 3/8-inch wide, was present in the -Y ET/SRB cable tray forward surface TPS. The presence of the crack was acceptable for flight per the NSTS-08303 criteria.

Less than usual amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Some ice and frost had formed at the LO2 feedline-to-umbilical interface 6 o'clock position. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were covered by some ice/frost and condensate.

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. Ice/frost had formed at the forward corner of the 17-inch flapper valve actuator access port foam plug. Ice/frost had also formed on the forward outboard and aft pyro canister closeout bondlines. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of three OTV recorded items:

Anomaly 001 documented an 4-inch by 3/8-inch crack in the forward surface TPS of the -Y vertical strut/ET-SRB cable tray.

Anomaly 002 documented ice/frost formations in the LO2 feedline support brackets and bellows.

Anomaly 003 documented ice/frost formations on the LO2 ET/ORB umbilical purge vents and the LH2 ET/ORB umbilical purge vents, recirculation line bellows, purge barrier, and forward outboard pyro canister closeout bondline.

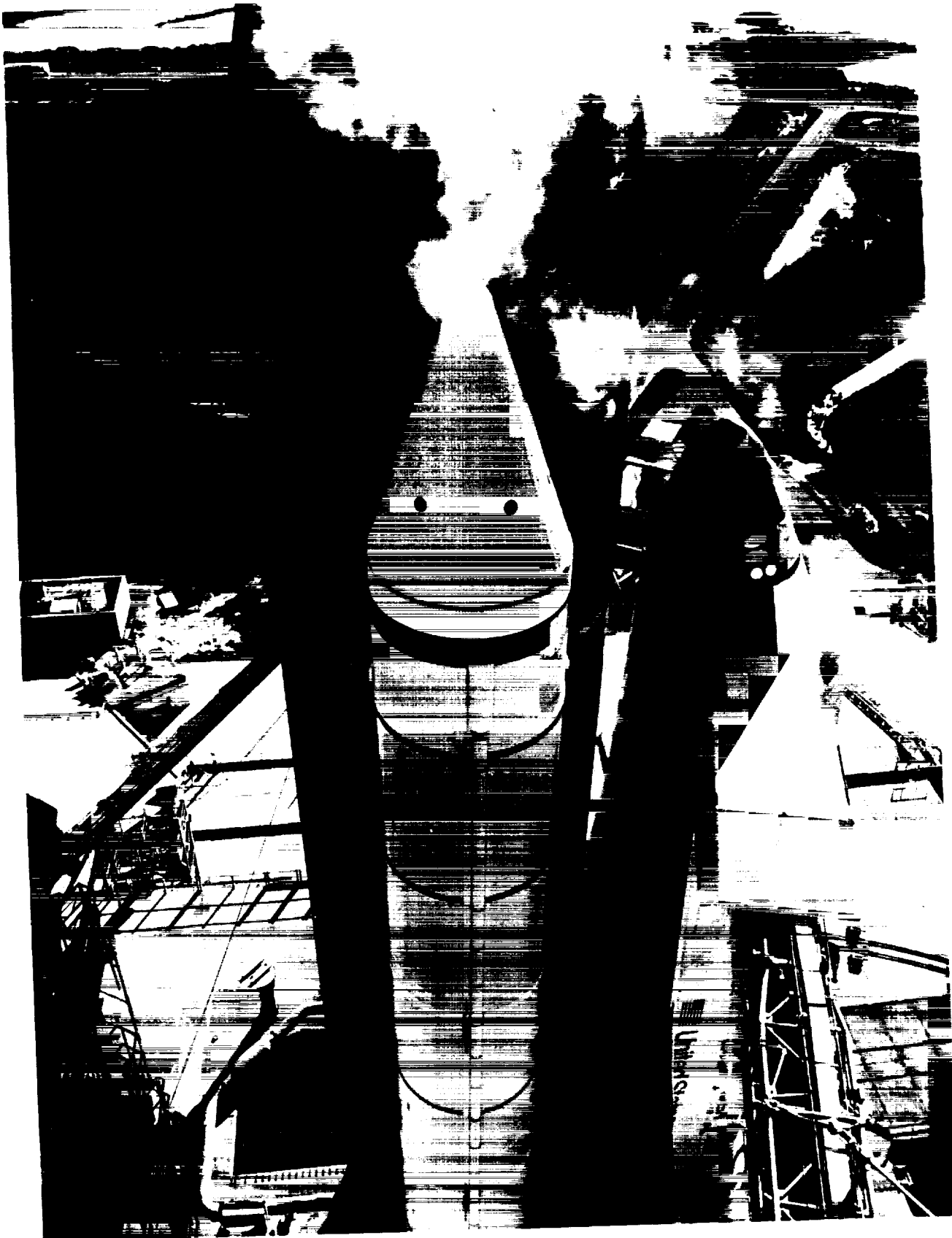
### **3.6 FACILITY**

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement).

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals, the GH2 vent line, or the Ground Umbilical Carrier Plate (GUCP).

No damage to the ET nosecone/footprint area was visible after the GOX vent hood was retracted. No dark spots or residue from the GOX seals were observed in the nosecone footprint area.





**Photo 2 : Overall View of STS-66 Vehicle**

OV-104 Atlantis (13th flight), ET-67 (LWT 60), and BI-069 SRB's  
No ice or TPS anomalies on the External Tank acreage



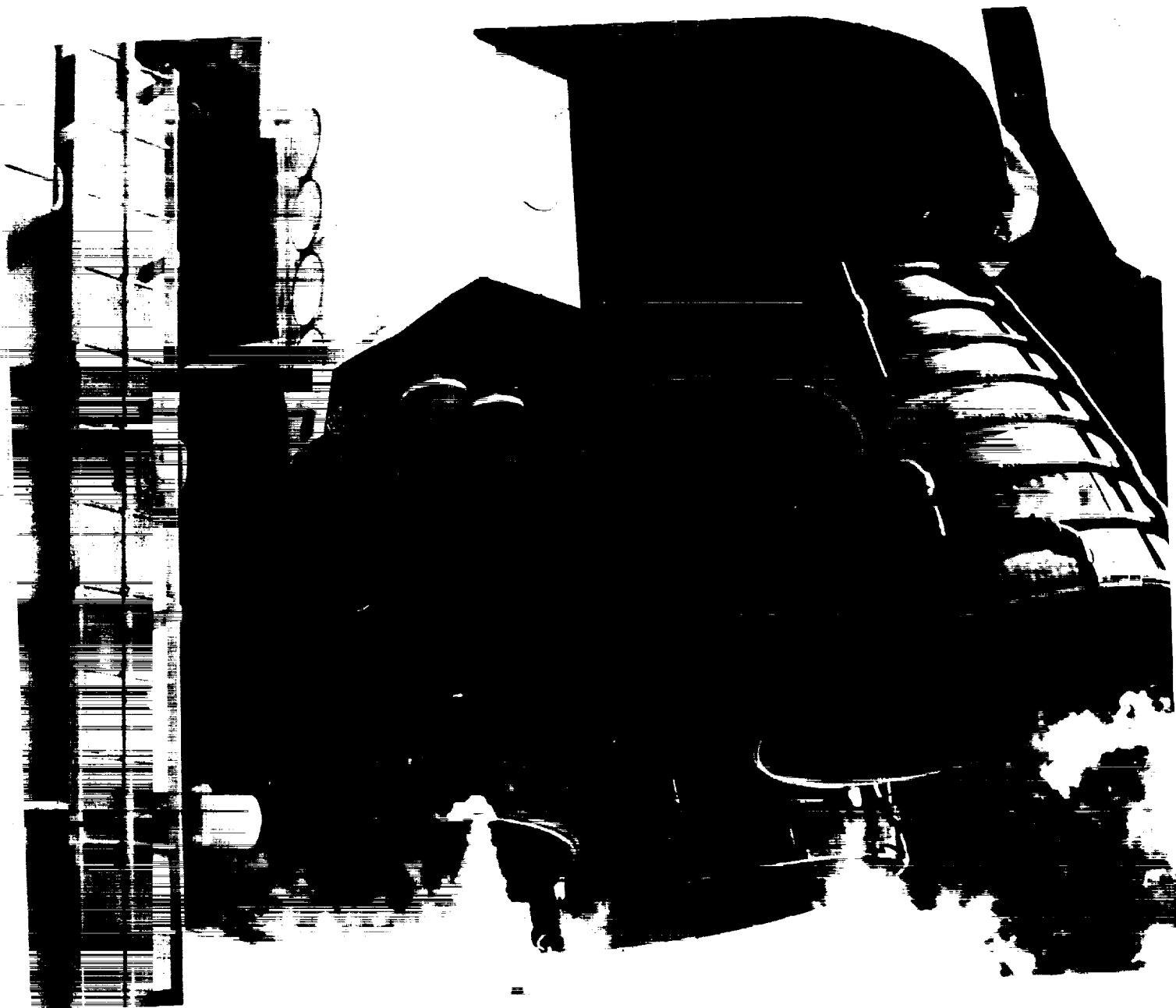


Photo 3 : Overall View of Main Engines





**Photo 4 : ET/ORB LH2 Umbilical**

Less than usual ice/frost had formed on the umbilical during cryoload



## 4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS and RSS was conducted on 3 November 1994 from 2.5 to 4 hours after launch.

No flight hardware or TPS materials were found. Facility debris found on the MLP deck included a one foot square piece of blue tarp, one metal part tag, and a chain hook.

South SRB HDP erosion was typical. All south HDP shoe EPON shim material was intact though numerous voids and pitting were observed in the sidewall shim material. There was no visual indication of a stud hang-up on any of the south holddown posts. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was typical. Most of the erosion had occurred on the HDP #7 and #8 covers. A crack was visible in the southwest corner of the HDP #4 cover. The SRB aft skirt purge lines and T-0 umbilicals exhibited typical exhaust plume damage.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA), and GOX vent arm appeared undamaged.

The GH2 vent line was latched on the 8th tooth of the latching mechanism, had no loose cables (static retract lanyard), and appeared to have latched properly with no rebound. However, minor damage to the GUCP cross brace may have been caused by contact with the static retract lanyard. Although the vent line came to rest centered in the haunch, paint damage on the north ratchet may be indicative of contact with the north side support during retraction.

Minor, but typical, pad damage included:

- Four broken stadium lights

- Numerous open and damaged access doors and cable tray covers

- FSS "215" and "255" foot level signs on the FSS grating

- 4-foot by 5-foot Herculite cover on the FSS 195 foot level grating

- Broken walkway lamp on the RSS 215 foot level

Walkdowns of the pad apron, flame trenches, and pad acreage were performed. No flight hardware or TPS material was found.

Post launch pad inspection anomalies are listed in Section 9.







**Photo 5 : North Holddown Post Blast Cover Erosion**



## 5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review. Post flight anomalies are listed in Section 9.

### 5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 97 films and videos, which included thirty-seven 16mm films, twenty 35mm films, three 70mm films, and thirty-seven videos, were reviewed starting on launch day.

No vehicle damage or lost flight hardware was observed that would have affected the mission.

Black residue from the GOX seals, which had appeared on the STS-64 and STS-68 ET nosecones, was not present on the STS-66 ET nosecone after the GOX vent hood was retracted (OTV 113, 160, 162). Lab analysis had shown the residue consisted of carbon and teflon with traces of rust. Compressor seals at Air Liquide Company were the most likely origin of the residue.

Several dark objects, believed to be silhouetted water drops from the facility deluge, fell close to the camera lens during ignition and liftoff (E-30).

SSME ignition, Mach diamond formation, and gimbal profile appeared normal (OTV 151, 170, 171). Three streaks occurred in the SSME #1 plume during startup (E-2, -3).

SSME ignition caused numerous pieces of ice to fall from the ET/Orbiter umbilicals. Some pieces of ice contacted the umbilical cavity sill and were deflected outward, but no tile damage was visible (OTV 109, 163, 164, E-34).

A black tile fragment, estimated to be 6 inches by 2 inches by 1 inch thick in size, fell aft near the body flap at GMT 16:59:40.375 (E-5, -18, -19). The tile fragment originated at the body flap hinge line area (+Z side) near the SSME #2 base mounted heat shield (E-77, frame 372). The tile fragment was shaken loose during SSME startup prior to Mach diamond formation. This fragment is also visible in film item E-52 at 16:59:40.127 GMT falling between the SSME #2 nozzle and the body flap.

A small piece of tile surface coating material was lost from the base heat shield near SSME #2 (E-18).

Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster occurred during engine start-up. The motion was similar to that observed on previous launches (E-76, -77).

Dust from the upper surface of the right wing fell aft of the elevons during SSME ignition (E-6).

The External Tank "twanged" approximately 32 inches during SSME ignition (E-79).

SRB ignition occurred at 16:59:43.013 GMT.

No stud hang-ups occurred on any of the holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes. A small, dark object, most likely a piece of hold down post shoe shim material, fell from the HDP #7 shoe into the SRB exhaust hole (E-11). All north holddown posts doghouse blast covers closed normally.

A cloth parts tag from the SRB sound suppression water troughs was ejected upward between the Orbiter and SRB's after T-0 (E-5). A second cloth parts tag was visible near HDP #7 (E-14, -16).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150; E-17, -18).

GUCP disconnect from the External Tank was nominal (OTV 104, 160, 167). GH2 vent line retraction was normal. However, excessive slack in the static retract lanyard caused contact with the GUCP 7-inch line quick disconnect (E-41, 42).

White objects at the edge of the SRB exhaust cloud are believed to be pieces of ice from the pad cross country cryogenic lines (E-60).

Large pieces of SRB throat plug moved north and upward out of the SRB flame trench soon after liftoff (E-62).

Pieces of ET/ORB umbilical ice continued to fall during early ascent (E-62).

A cluster of particles, most likely pieces of FRCS thruster paper covers, were visible falling aft along the right side of the Orbiter at 17:00:05.198 GMT (E-59).

Numerous small SRB propellant particles fell aft near the SRB plumes during ascent (E-220, -223, -224; E-59: two at 17:00:11.642, two more at 17:00:14.308). More particles were observed near the SRB exhaust plumes between 65 and 82 seconds MET.

A piece of ET/ORB umbilical purge barrier material fell aft during the roll maneuver (E-207, frame 1706). Two more pieces appeared aft of the body flap (E-207, frame 3027). Later in flight, another piece entered the SSME plume and caused a flash (E-222, 17:00:30.016 GMT).

Three more flashes, typically caused by debris from purge barrier material or RCS thruster paper covers, occurred in the SSME plume during ascent (E-222).

Body flap movement (amplitude and frequency) was similar to previous flights (E-207, -212, -213).

Programmed movement of the elevons for load relief during ascent was visible (E-207, -212).

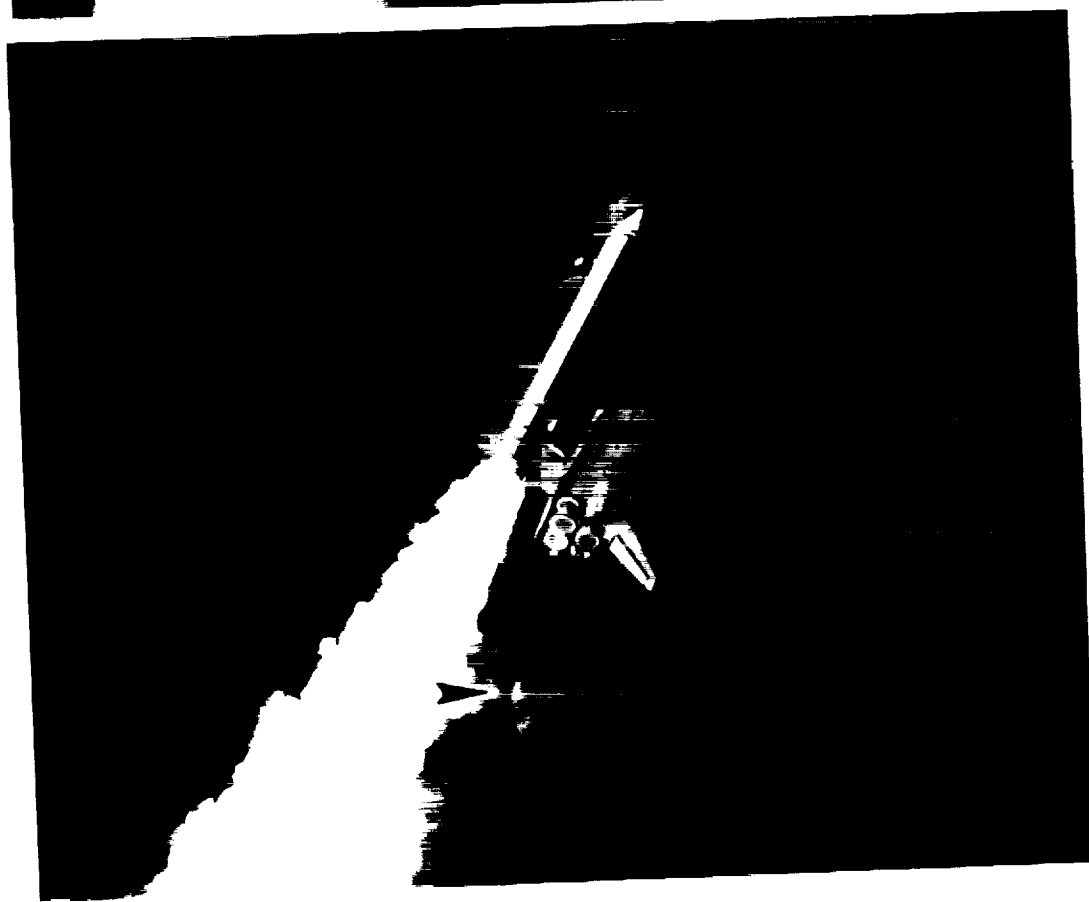
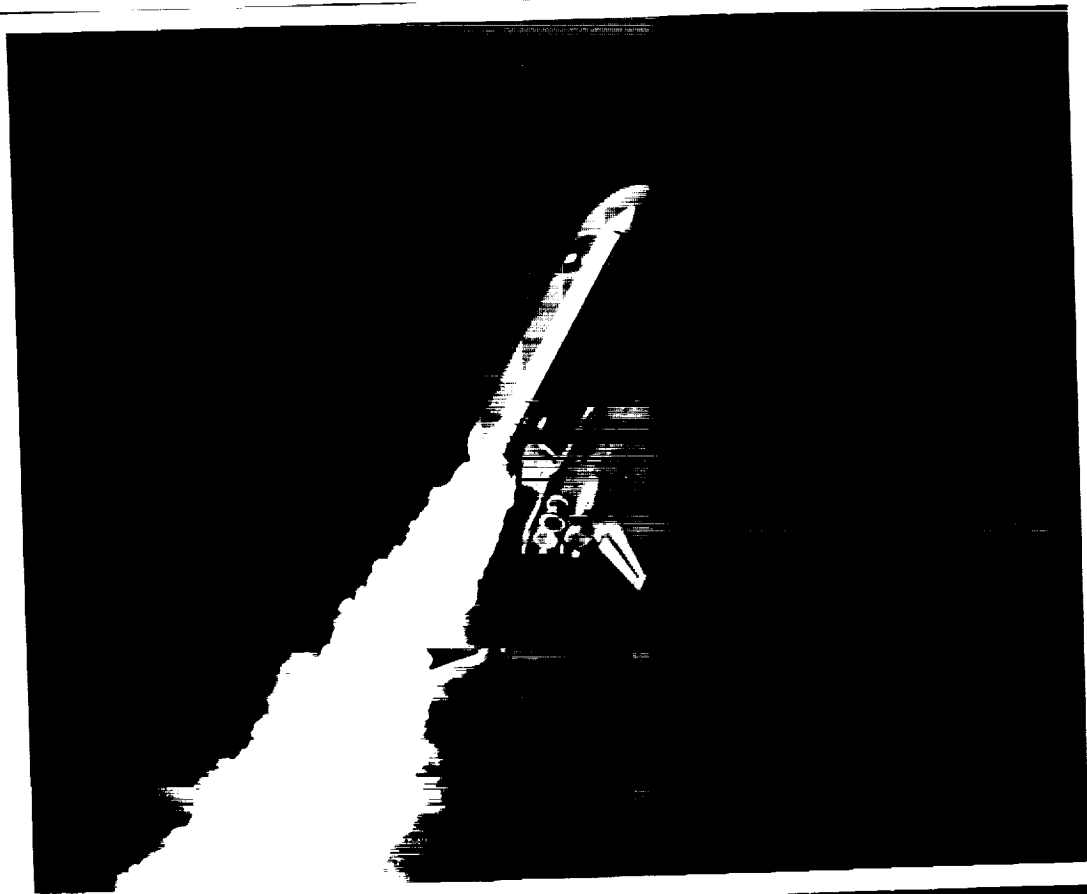
ET aft dome charring, though occurring early in the flight, was typical. SRB plume tailoff and separation appeared normal. Numerous pieces of slag dropped out of the SRB plume before, during, and after separation (E-207, -208, -212, -220).



**Photo 6 : Loss of Tile Fragment from Body Flap Hinge**

The black tile fragment, visible against the SSME #2 white DMHS closeout blanket and dark bell nozzle (arrows), was shaken loose during SSME ignition at approximately T-2.6 seconds MET





**Photo 7 : Flash in SSME Plume Caused by Debris**

Typical sequence shows debris, such as ET/ORB umbilical purge barrier material or RCS thruster paper cover, falling into SSME exhaust plume and causing an orange flash (arrows)





## 5.2 ON-ORBIT FILM AND VIDEO SUMMARY

DTO-0312 was performed by the flight crew. Twenty-two hand-held 35mm still images and some video were obtained of the External Tank after separation from the Orbiter.

OV-104 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Data was obtained from all sources.

No vehicle damage or lost flight hardware was observed that would have been a safety of flight concern.

Solid Rocket Booster separation from the External Tank was nominal.

Vapors in the vicinity of the LH SRB aft booster factory joints and ETA ring were identified as exhaust plume recirculation vapors backlit by the sun.

External Tank separation from the Orbiter was nominal.

The BSM burn scars on the LO2 tank were typical. No anomalies were observed on the nosecone, PAL ramps, RSS antennae, flight door, LO2 feed line, and aft hard point. Erosion of the manhole cover closeouts and aft dome apex was also typical.

Two TPS divots were observed on the LO2 tank at or near the LO2 pressurization line ramps: one 4-inch divot at approximately XT-514; one 9-inch divot at approximately XT-676.

Three stringer head divots were observed on the intertank acreage: one 14-inch divot just forward of the -Y bipod spindle housing closeout; one 17-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods; and one 24-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods. (This type of divot had been the subject of a previous IFA. Manufacturing procedures at the factory were modified, effective on ET-74, to reduce the potential for TPS damage during intertank assembly).

Four divots were present in the LH2 tank-to-intertank flange closeout: one 5-inch divot in the -Y+Z quadrant; one 7-inch divot adjacent to the -Y bipod spindle housing closeout; and two 5-inch divots to the +Y side of the PAL ramp.

Both bipod jack pad closeouts were intact and appeared to be in excellent condition.

The LH2 tank acreage was generally in good condition with the exception of one shallow divot aft of the bipods and numerous shallow "popcorn" type divots forward of the crossbeam in the lower third area of the barrel section.

LO2 feedline and +Y thrust strut flange closeouts exhibited minor erosion. Ice was still present in the LO2 feedline lower bellows.

The LH2 ET/ORB umbilical appeared to be in good condition with little or no TPS damage. The red purge seal was intact. Blistering of the fire barrier coating was typical. Frozen hydrogen adhered to the 17-inch flapper valve. Foam was missing or eroded from the horizontal (clamshell) section of the cable tray and the aft surface of the -Y vertical strut.

The LO2 ET/ORB umbilical sustained little or no TPS damage. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. The red purge seal was intact. The lightning contact strip across the forward part of the umbilical was missing and observed drifting near the umbilical area.

Video footage of the ET after separation showed venting of residual gases from the ET/ORB umbilicals. Pieces of frozen hydrogen originated from the LH2 ET/ORB umbilical and drifted away from the tank. This activity was expected and had been previously documented on the STS-45, STS-53, and STS-68 missions.

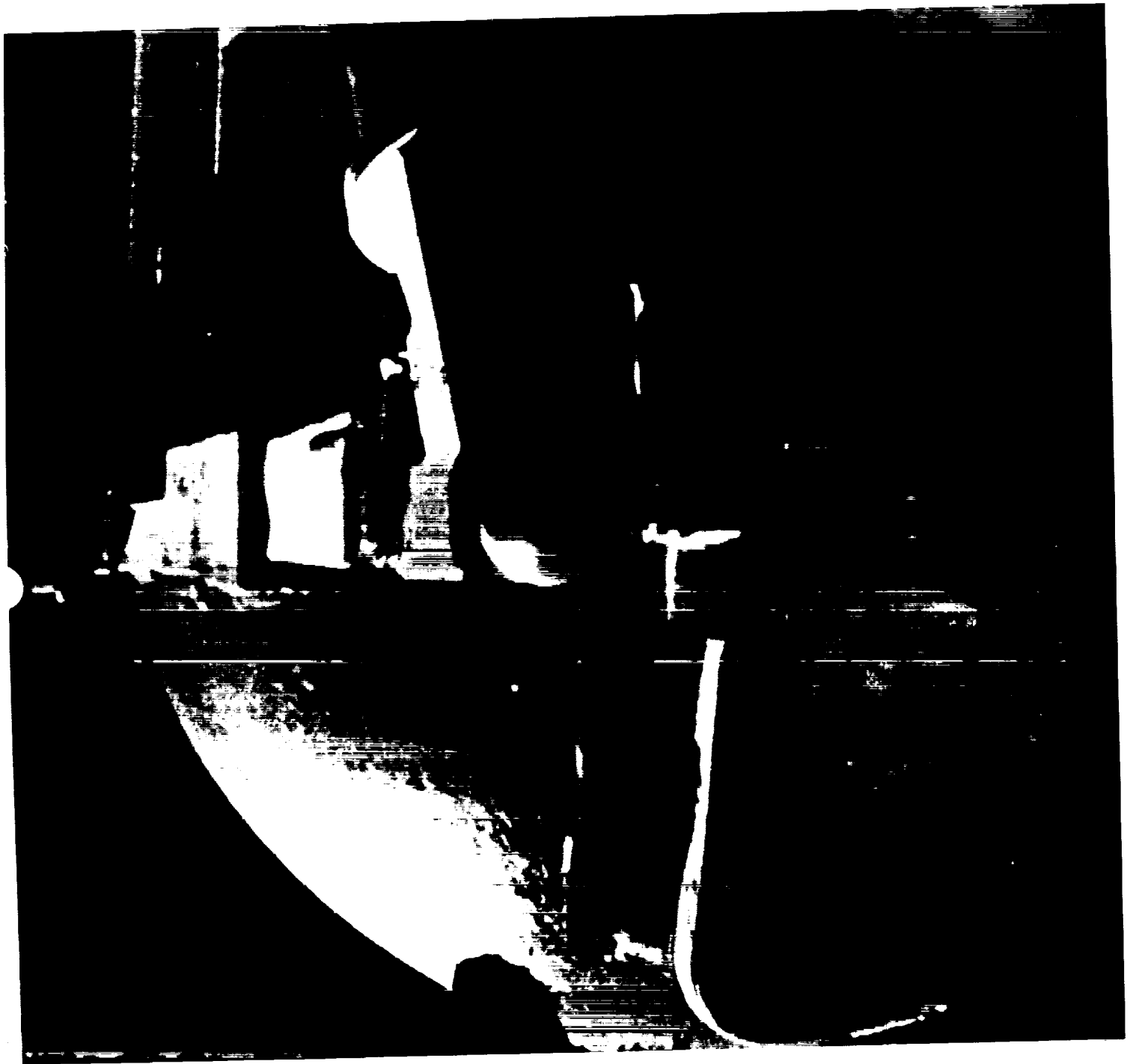
Video taken from the RMS wrist camera showed liquid expelled from the supply water dump nozzle on the port side of the Orbiter near the crew hatch. The video also revealed the water had frozen, adhered to the port payload bay door, and formed an icicle estimated to be at least 4 feet in length. No camera coverage of payload bay door closing was available to determine the amount of ice still attached to the outer surface of the door. Some of this ice, which broke off and fell aft during re-entry, is believed to be the cause of tile damage on the RH OMS pod leading edge and the vertical stabilizer. Post landing inspections and film review showed ice still adhering to the left payload bay door after rollout and wheel stop.



**Photo 8 : Nominal SRB Separation from External Tank**

Charring and erosion of the TPS on the aft surfaces of the ET/ORB LH2 umbilical cable tray and -Y vertical strut was typical. The sun's position behind the left SRB caused the bright spots on the SRB ETA ring and External Tank aft dome insulation (arrows).

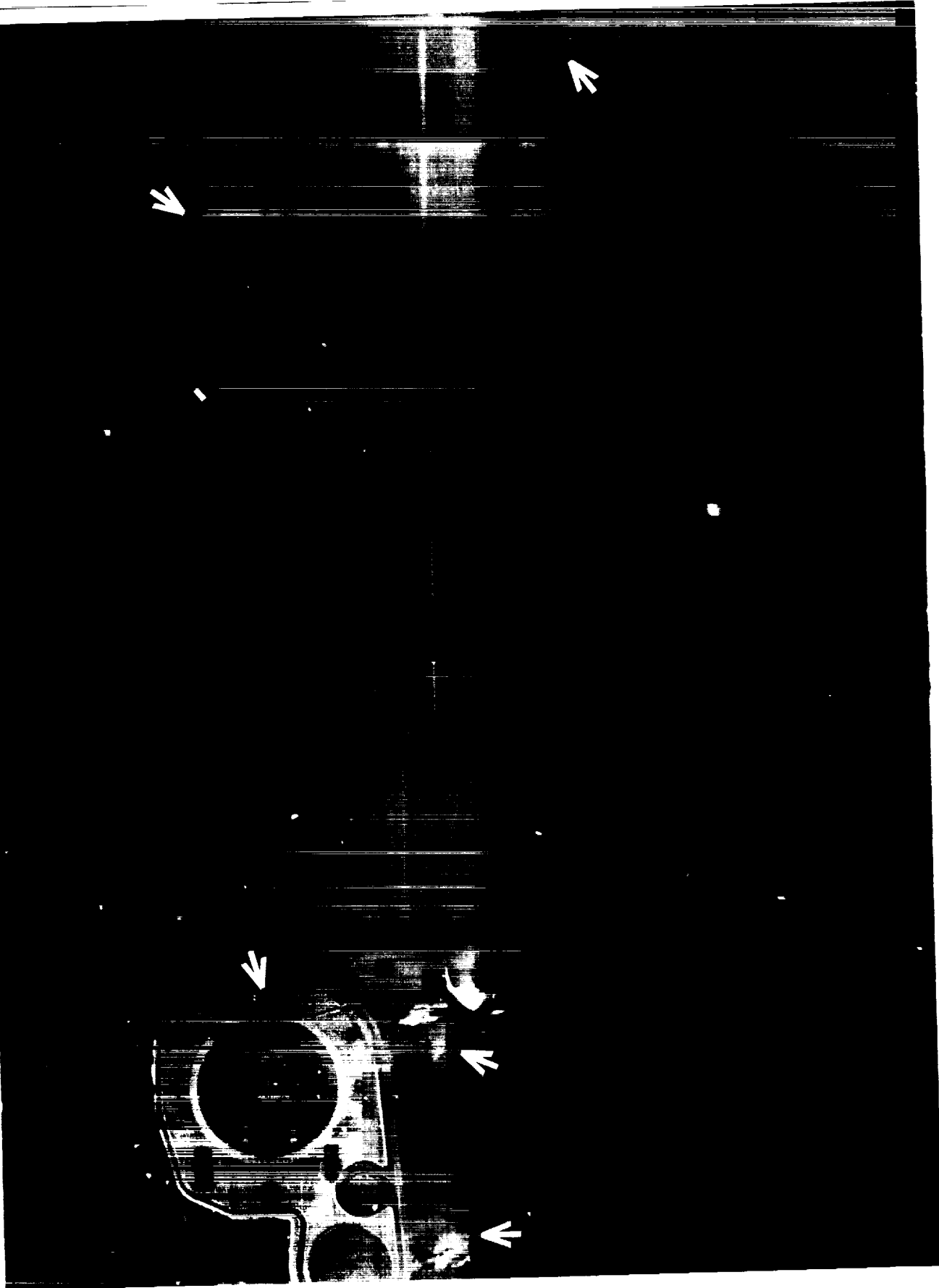




**Photo 9 : Nominal ET Separation from Orbiter**

The LH2 ET/ORB umbilical appeared to be in good condition with little or no TPS damage. Blistering of the fire barrier on the outboard side of the umbilical was typical. Frozen hydrogen adhered to the 17-inch flapper valve.





**Photo 10 : View of LO2 ET/ORB Umbilical and Feedline**

The LO2 umbilical sustained little TPS damage. Foam was missing from the cable tray. The lightning contact strip across the forward part of the umbilical was missing. Note shallow divots on the LH2 tank TPS acreage; erosion on the LO2 feedline and thrust strut flange closeouts.

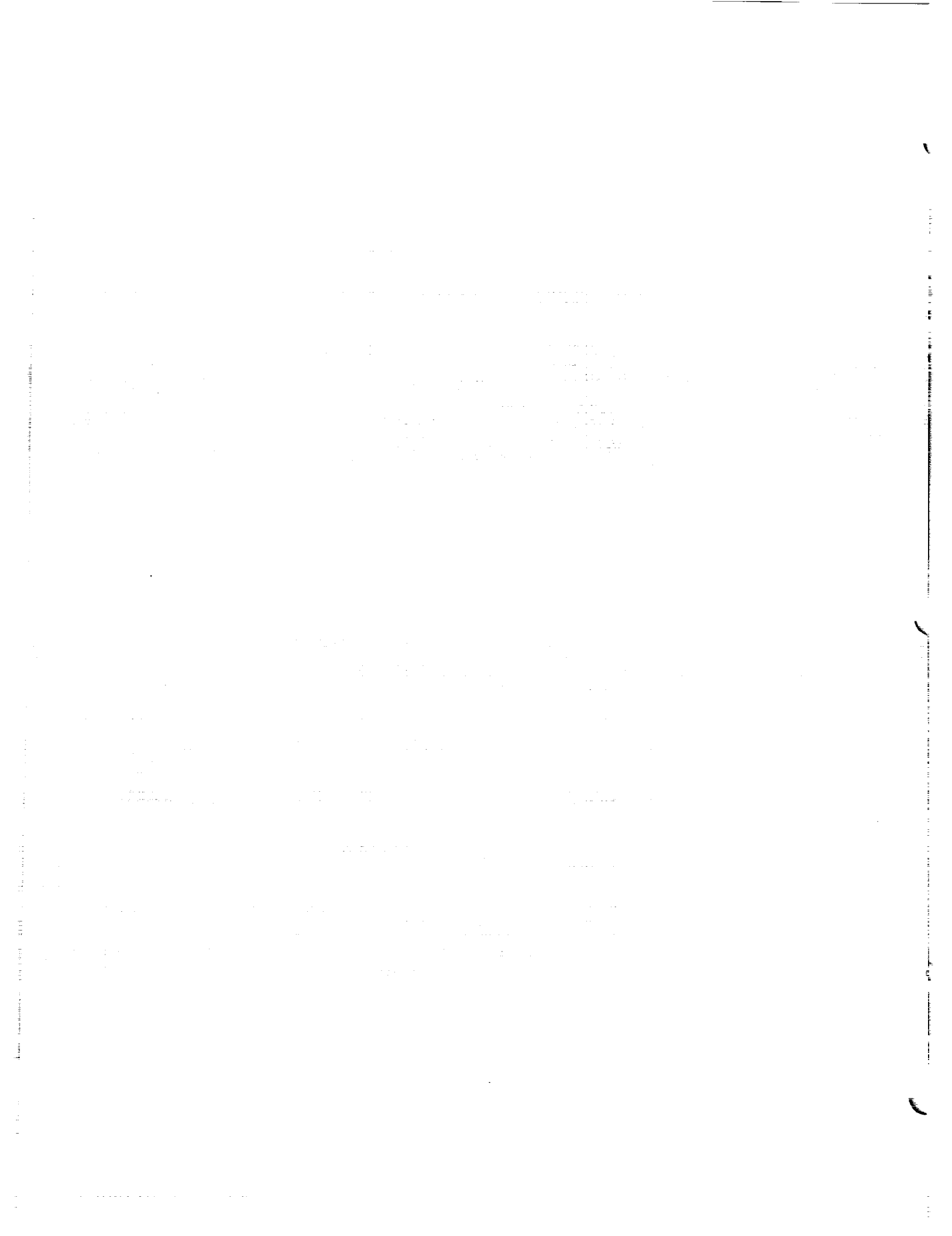


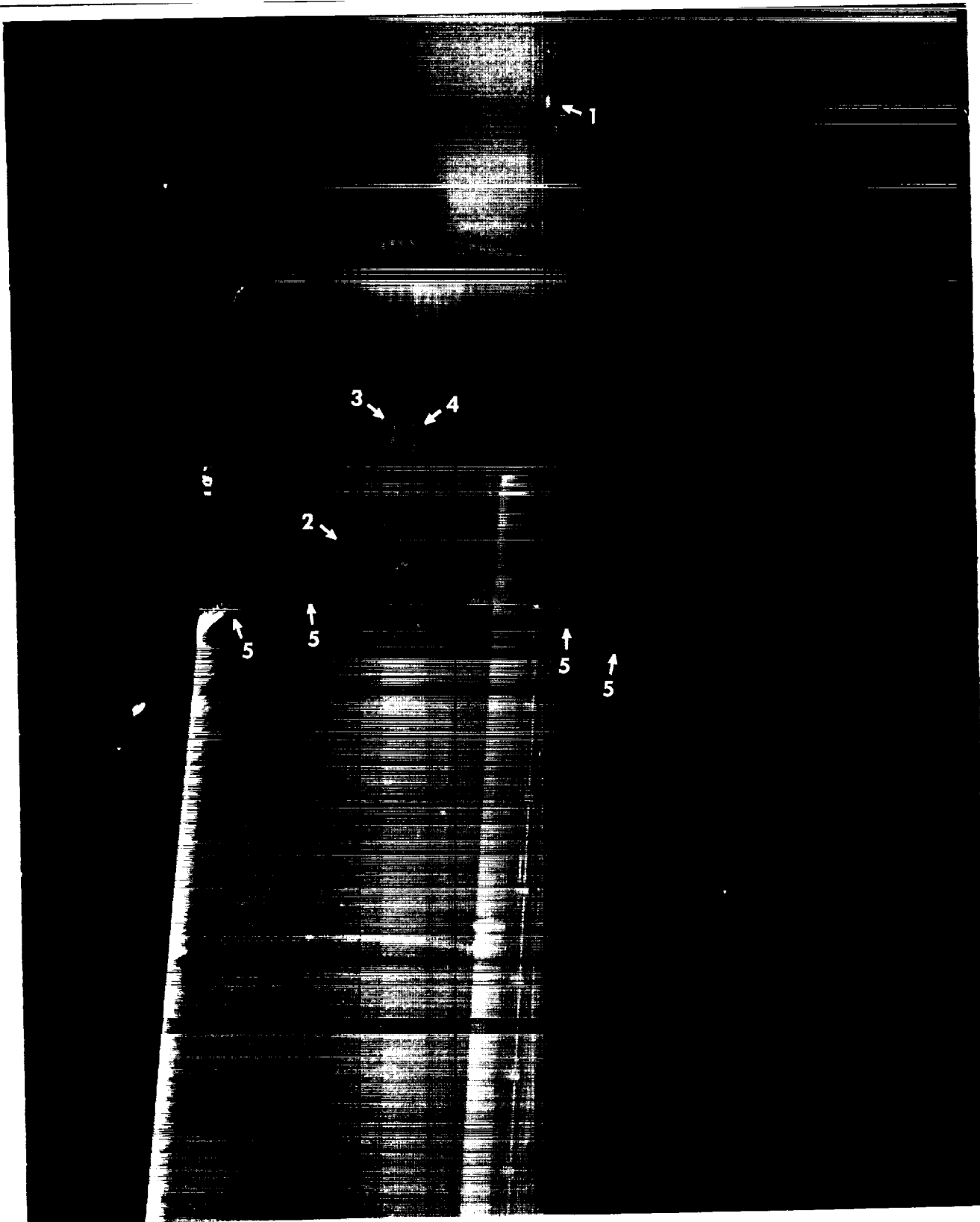




**Photo 11 : Free Floating Lightning Contact Strip**

The lightning contact strip, detached from the forward part of the LO2 ET/ORB umbilical, reflected sunlight while drifting away from the umbilical area.





**Photo 12 : View of Jack Pad Closeouts and +Z Acreage**

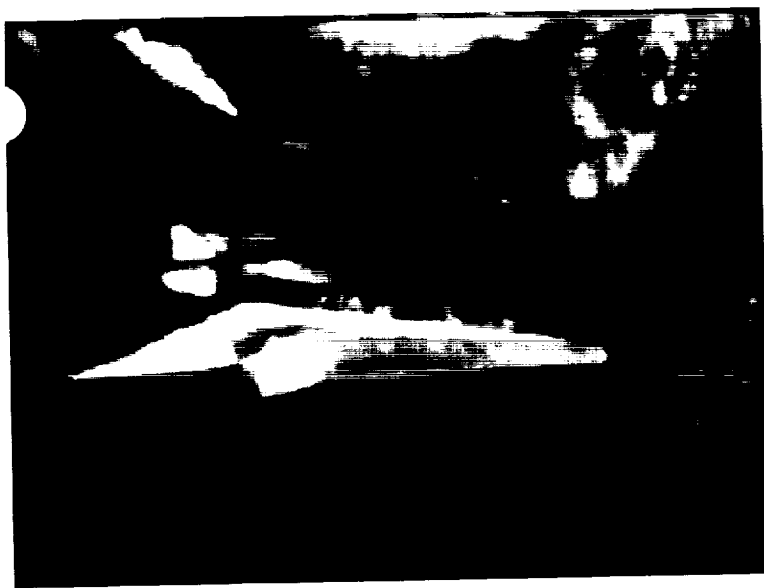
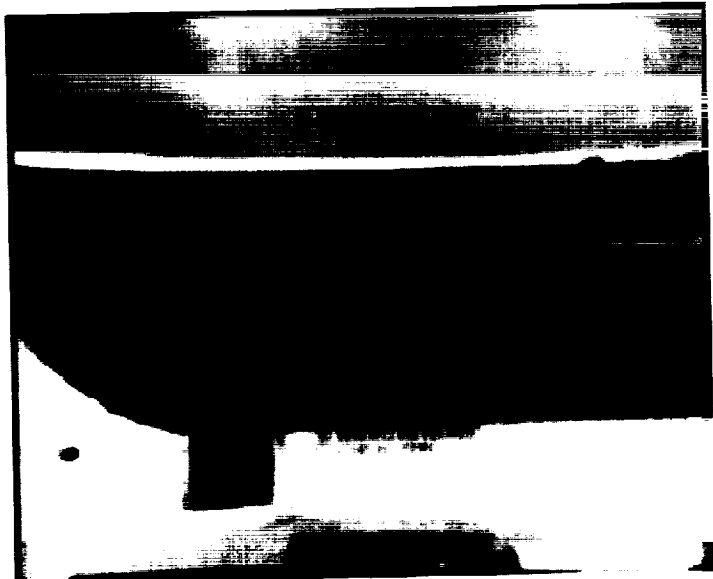
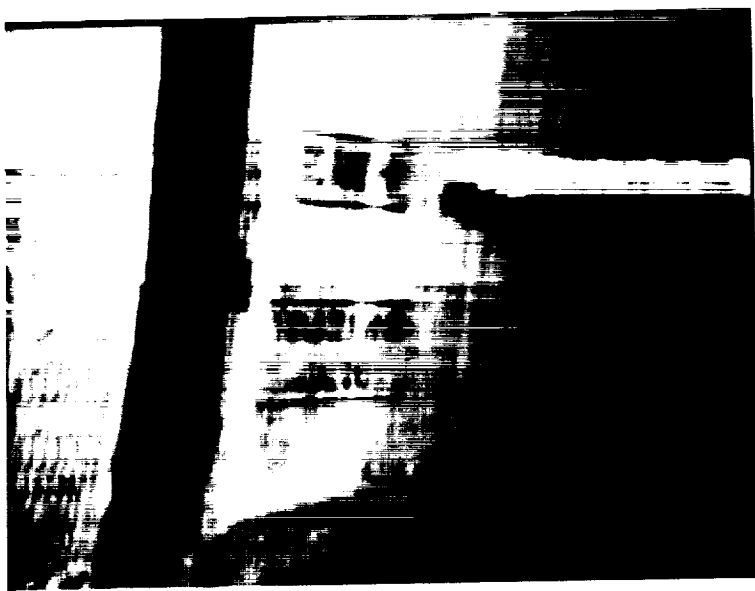
One 9-inch divot was visible on the LO2 tank at or near the LO2 pressurization line ramp (arrow #1). Three stringer head divots occurred on the intertank acreage: one 14-inch divot just forward of the -Y bipod spindle housing closeout (#2); one 17-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods (#3); and one 24-inch by 3.5-inch divot with exposed substrate on the +Z axis forward of the bipods (#4). Four divots were present in the LH2 tank-to-intertank flange closeout (#5). Both bipod jack pad closeouts were intact and appeared to be in excellent condition.





**Photo 13 : Pre-Launch View of ET Intertank/Bipods**





**Photo 14 : Icicle Formation on Payload Bay Door**

The RMS wrist camera showed liquid expelled from the supply water dump nozzle (upper left photo) on the port side of the Orbiter near the crew hatch. The video also revealed the water had frozen, adhered to the port payload bay door (upper right photo), and formed an icicle estimated to be at least 4 feet in length (lower left and lower right photos).





### **5.3 LANDING FILM AND VIDEO SUMMARY**

Eight 16mm films, two 35mm large format films, and four videos of landing were reviewed.

Orbiter performance on final approach appeared normal. There were no anomalies when the landing gear was extended. Touchdown of the left and right main gear was nominal and virtually simultaneous.

The drag chute was deployed after breakover, but before the nose gear contacted the runway. Drag chute deployment appeared nominal. Two pieces of black material, which are made of Teflon cloth and used in packing of the chute to prevent abrasion, came loose during chute deployment and fell to the runway.

Touchdown of the nose landing gear was smooth.

Rollout and wheel stop were uneventful. No large tile damage sites were visible on the Orbiter lower surface. However, two damage sites were observed on the RH OMS pod leading edge tiles. Ice still adhered to the left payload bay door #1 panel. This ice was the remnant of the 4-foot icicle formed on-orbit by the supply water dump.

## **6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT**

Both Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 7 November 1994. From a debris standpoint, both SRB's were in good condition.

### **6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION**

The RH frustum was missing no TPS but had 50 debonds over fasteners and 2 debonds over acreage (Figure 1). Since the number of debonds was greater than the frustum history average of 25 debonds, a representative set of the MSA-2 debonds were analyzed by MSFC for possible material or processing anomalies (IFA: MSA-2 did not adhere to painted surfaces adjacent to PR 1422-sealant-over-fastener debonds. The problem was traced to an MSA-2 spray pump problem). Hypalon paint was blistered/missing where BTA closeouts had been applied. Some of the underlying BTA was sooted. The BSM aero heat shield covers had locked in the fully opened position.

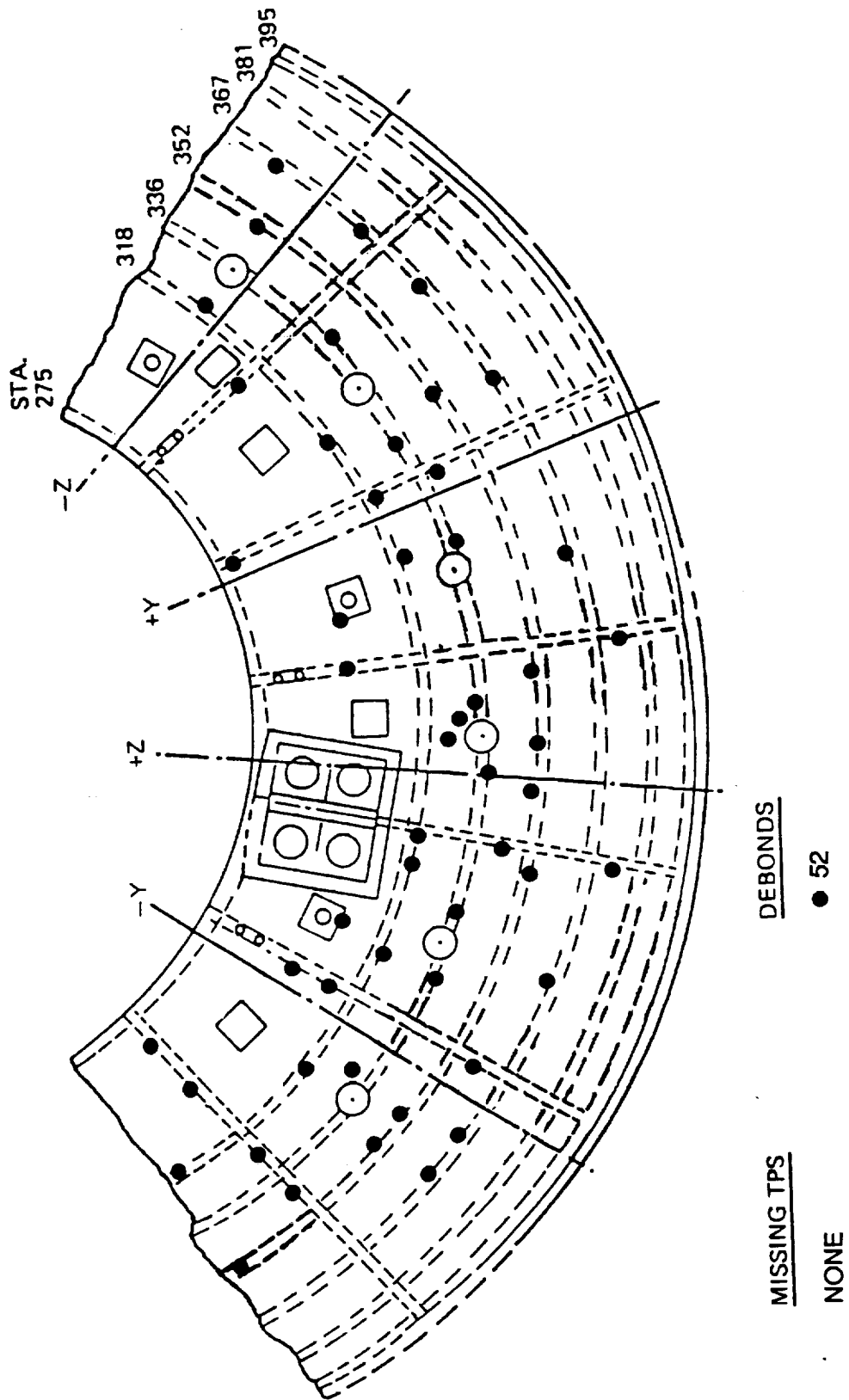
The RH forward assembly was missing no TPS but had one debond near the +Z RSS antenna between the 492 and 523 ring frames. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA had been applied. No pins were missing from the frustum severance ring.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. A 2-inch debond occurred in the forward factory joint 145 degree location. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

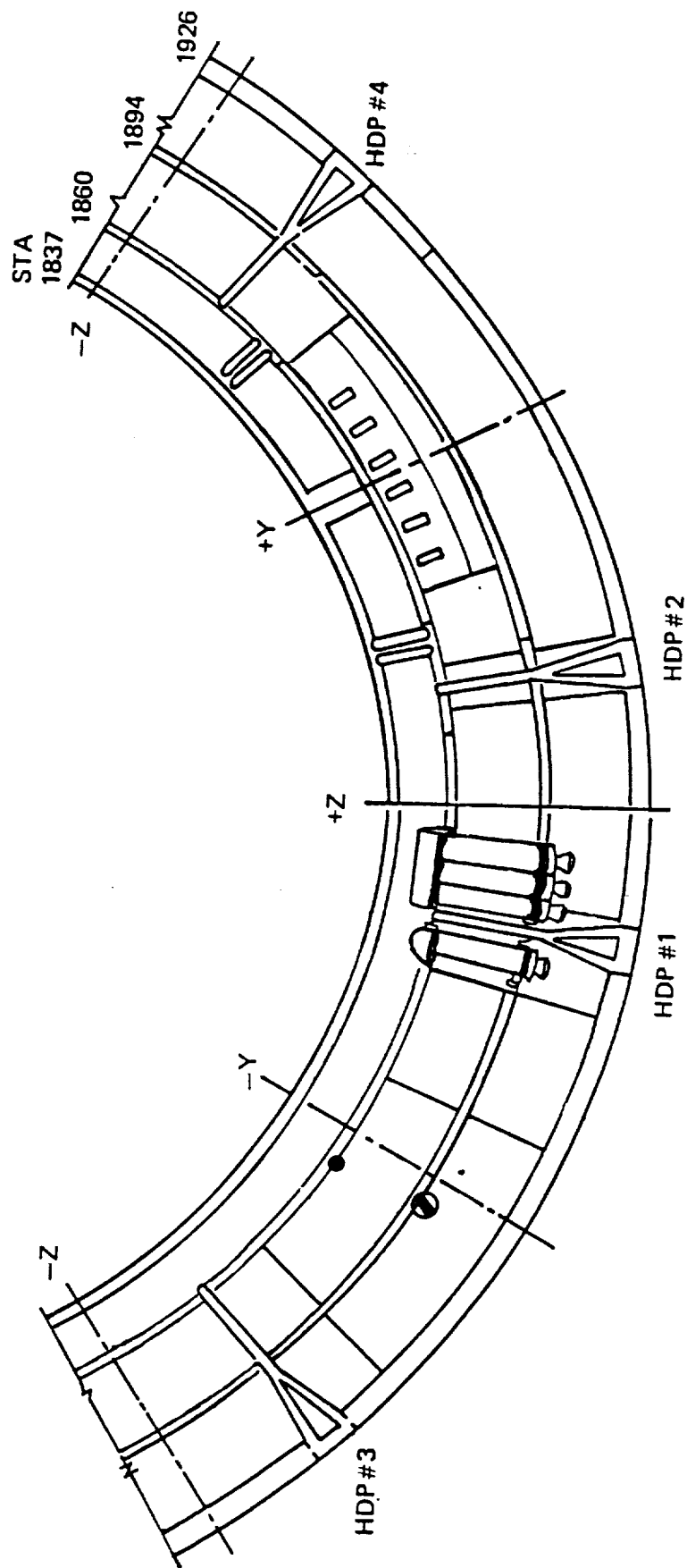
The phenolic material on the kick ring exhibited minor delamination. Aft skirt acreage TPS was generally in good condition. One MSA-2 debond occurred near the -Y axis at the XB-1860 ring frame. A 2-inch diameter MSA-2 divot was present near the -Y axis at the XB-1894 ring frame (Figure 2). Hypalon paint was blistered/missing over the areas where BTA had been applied. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.


**STS-66  
RIGHT SRB FRUSTUM**




**Figure 1 : RH SRB Frustum**

**STS-66**  
**RIGHT SRB AFT SKIRT EXTERIOR TPS**



**MISSING TPS**  1

**DEBONDS**  1

**ALL DCS PLUNGERS PROPERLY SEATED**

**Figure 2 : RH SRB Aft Skirt**



**Photo 15 : RH Frustum**

The RH frustum was missing no TPS but had 50 MSA-2 debonds over fasteners and 2 debonds over acreage. The BSM aero heat shield covers had locked in the fully opened position.



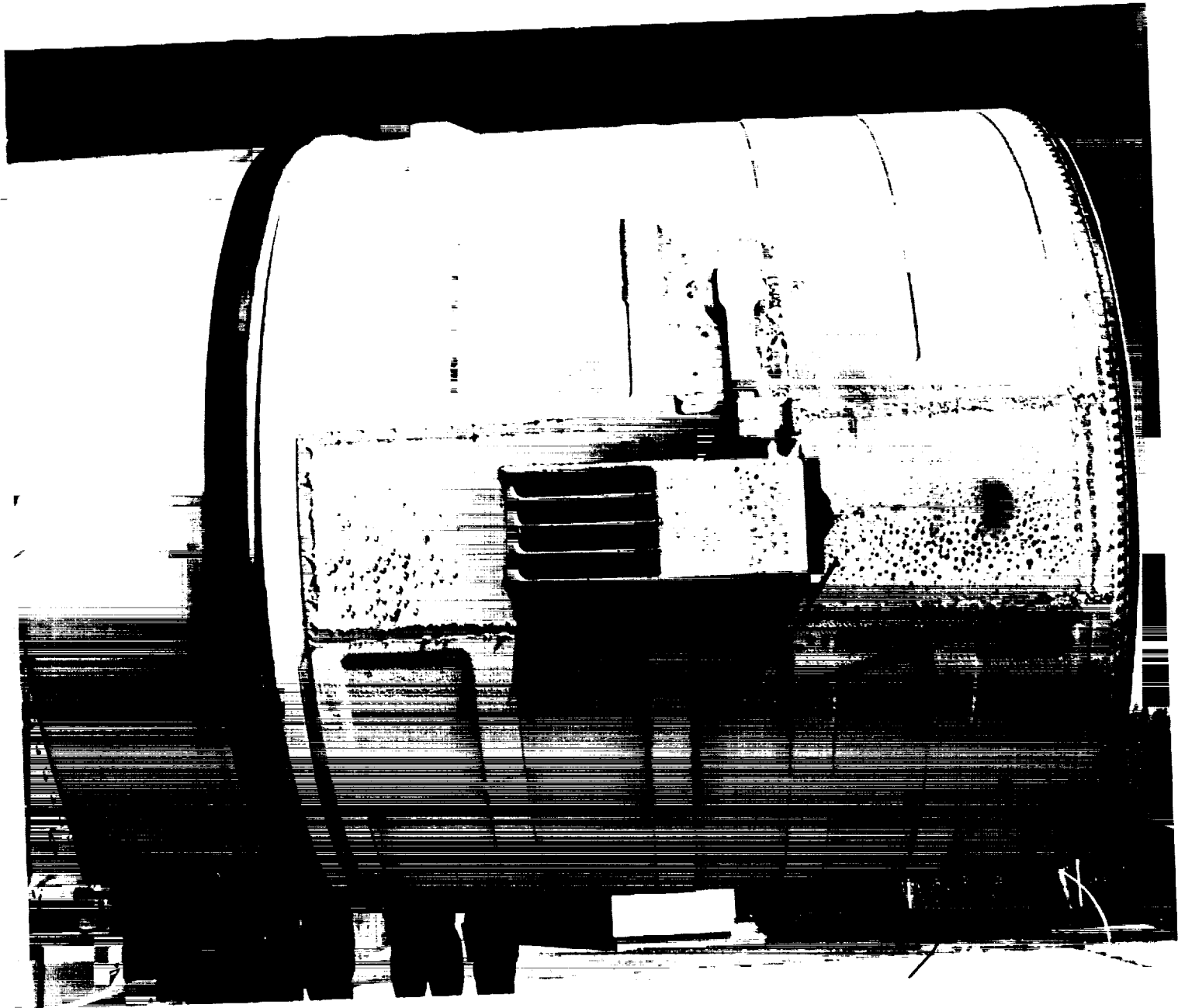


Photo 16 : RH Forward Assembly





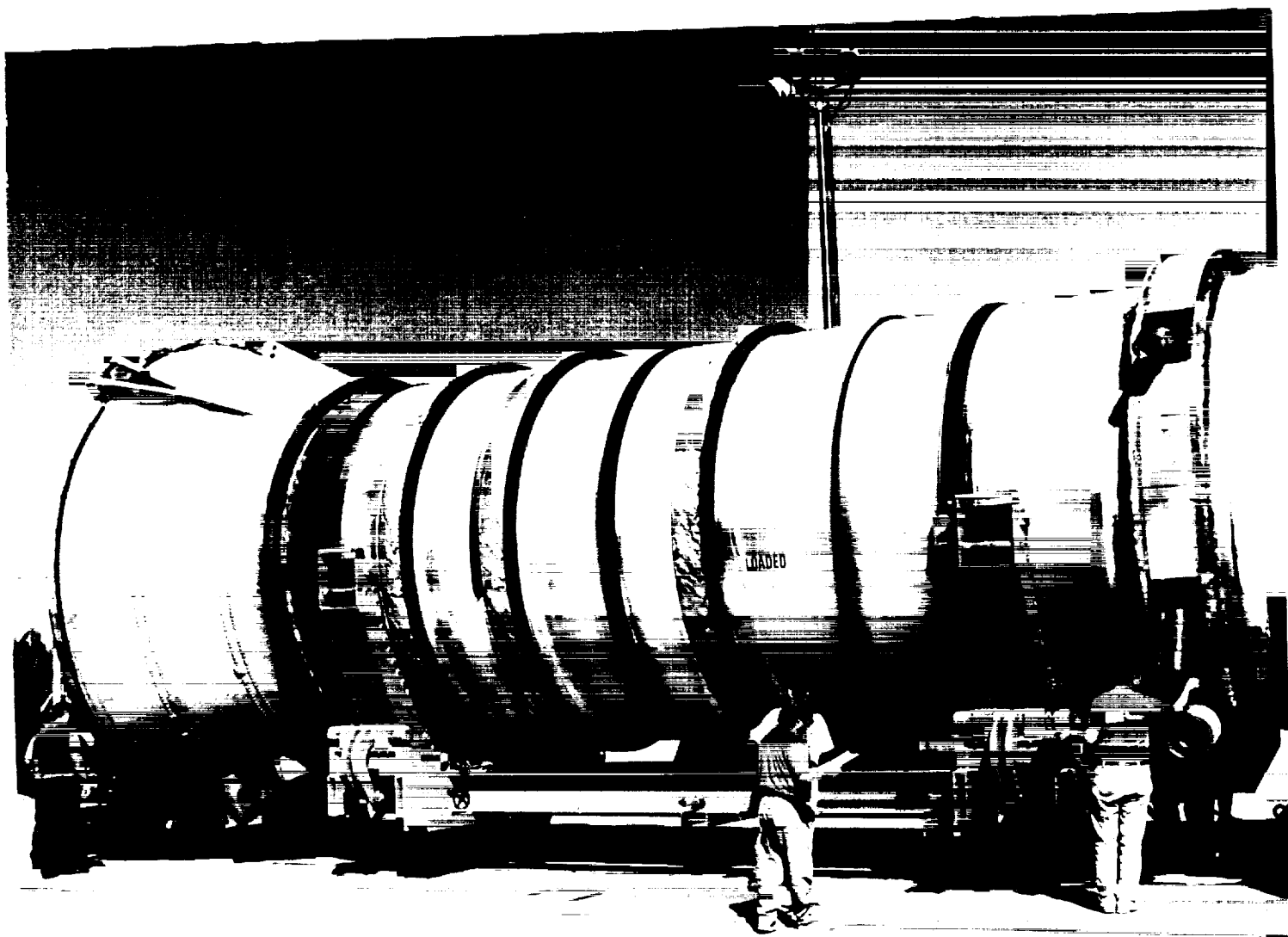


Photo 17 : RH Aft Booster/Aft Skirt



## **6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION**

The LH frustum was missing no TPS but had 39 MSA-2 debonds over fasteners (Figure 3). Since the number of debonds was greater than the frustum history average of 25 debonds, a representative set of the MSA-2 debonds were analyzed by MSFC for possible material or processing anomalies (IFA: MSA-2 did not adhere to painted surfaces adjacent to PR 1422-sealant-over-fastener debonds. The problem was traced to an MSA-2 spray pump problem). Hypalon paint was blistered/missing where BTA had been applied. Some of the underlying BTA was sooted. The BSM aero heat shield covers had locked in the fully opened position.

The LH forward assembly acreage exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Blistering of the Hypalon paint occurred near the ET/SRB attach point where BTA had been applied. No pins were missing from the frustum severance ring.

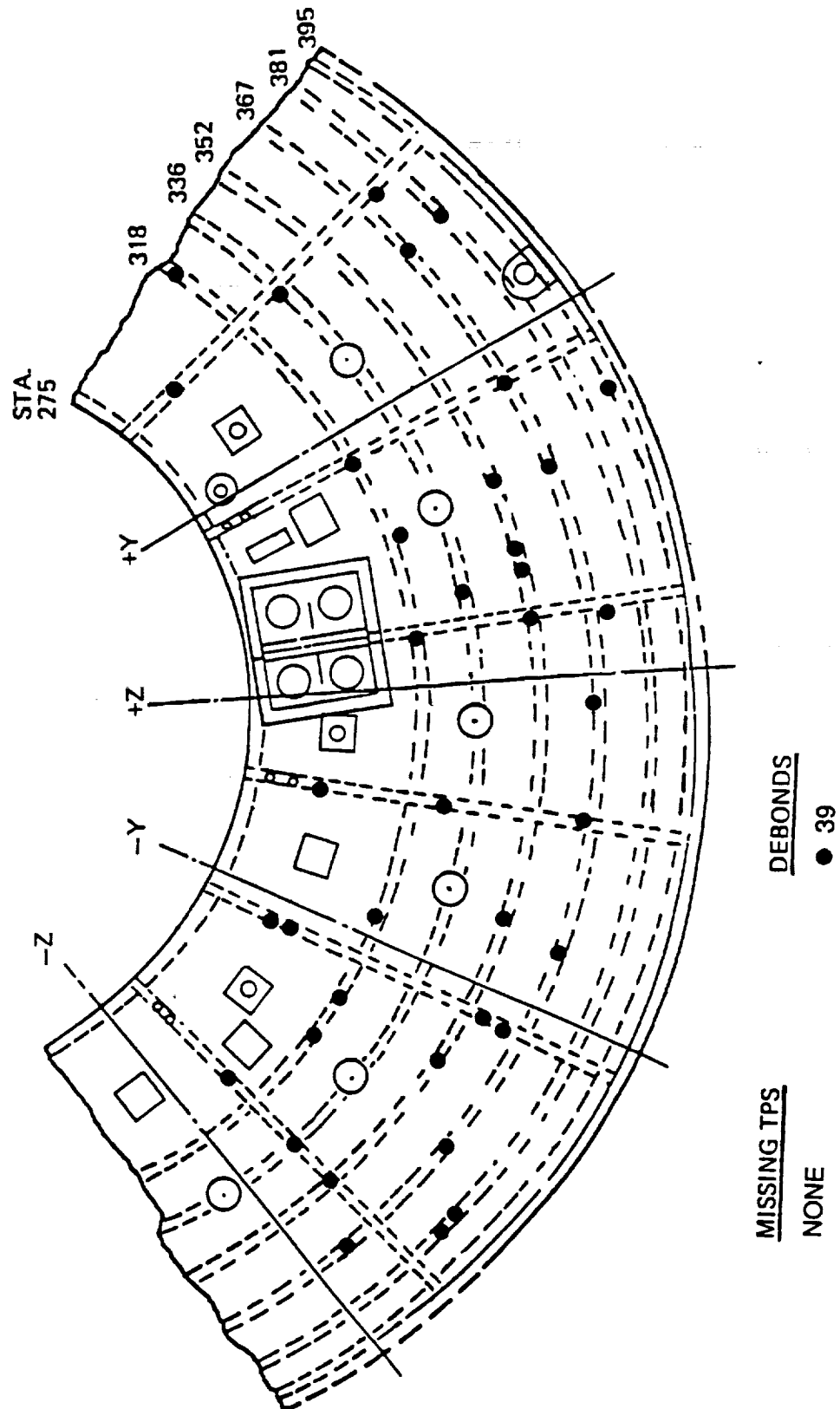
The Field Joint Protection System (FJPS) closeouts were in good condition. In general, minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged. One stiffener ring was damaged by water impact. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

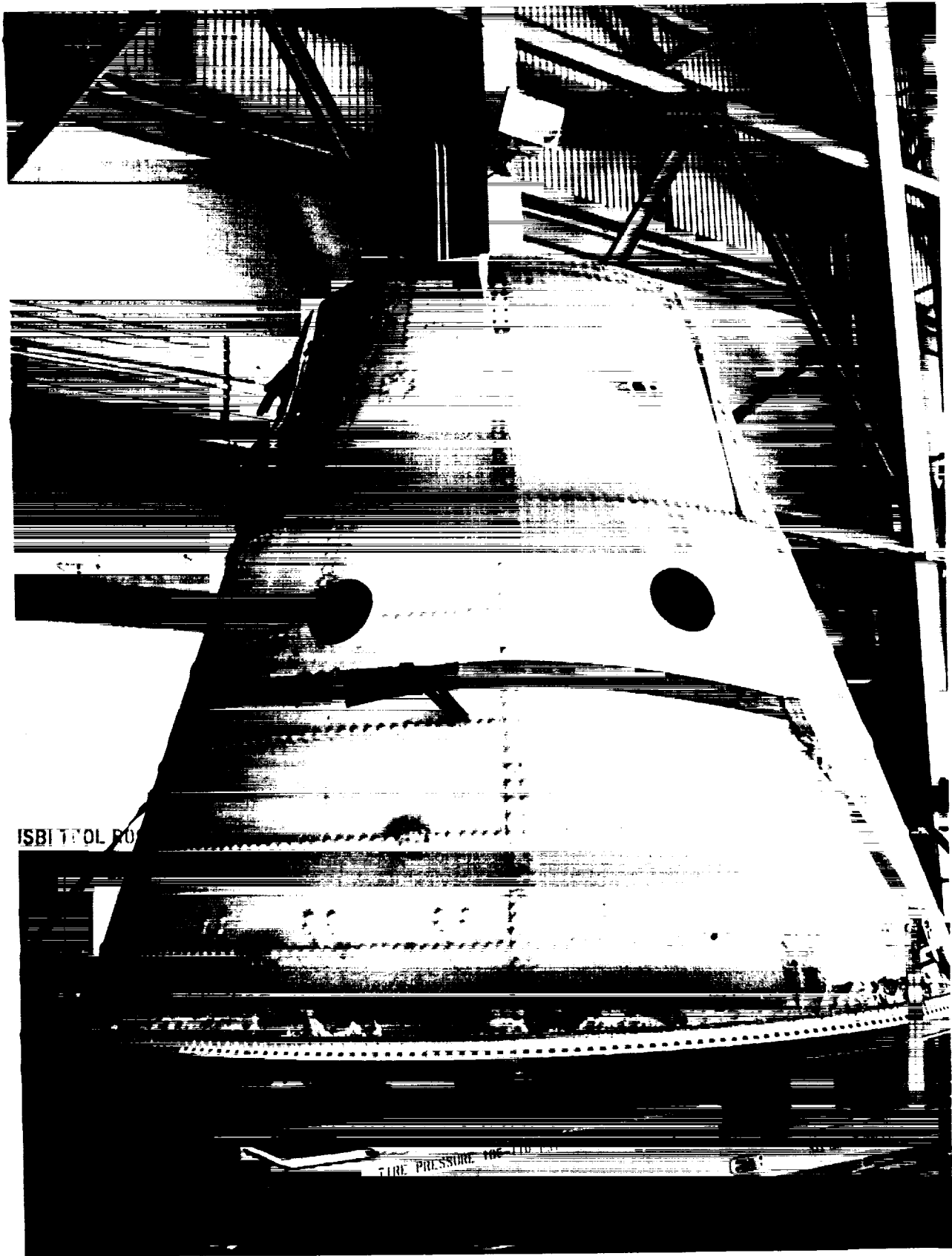
Three layers of phenolic material had delaminated on the kick ring - a typical occurrence. Aft skirt acreage TPS was generally in good condition. Hypalon paint was blistered over areas where BTA had been applied. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.

SRB Post Launch Anomalies are listed in Section 9.

**STS-66  
LEFT SRB FRUSTUM**



**Figure 3 : LH SRB Frustum**



**Photo 18 : LH Frustum**

The LH frustum was missing no TPS but had 39 MSA-2 debonds over fasteners. Hypalon paint was blistered/missing where BTA closeouts had been applied. All BSM aero heat shield covers had locked in the fully opened position.



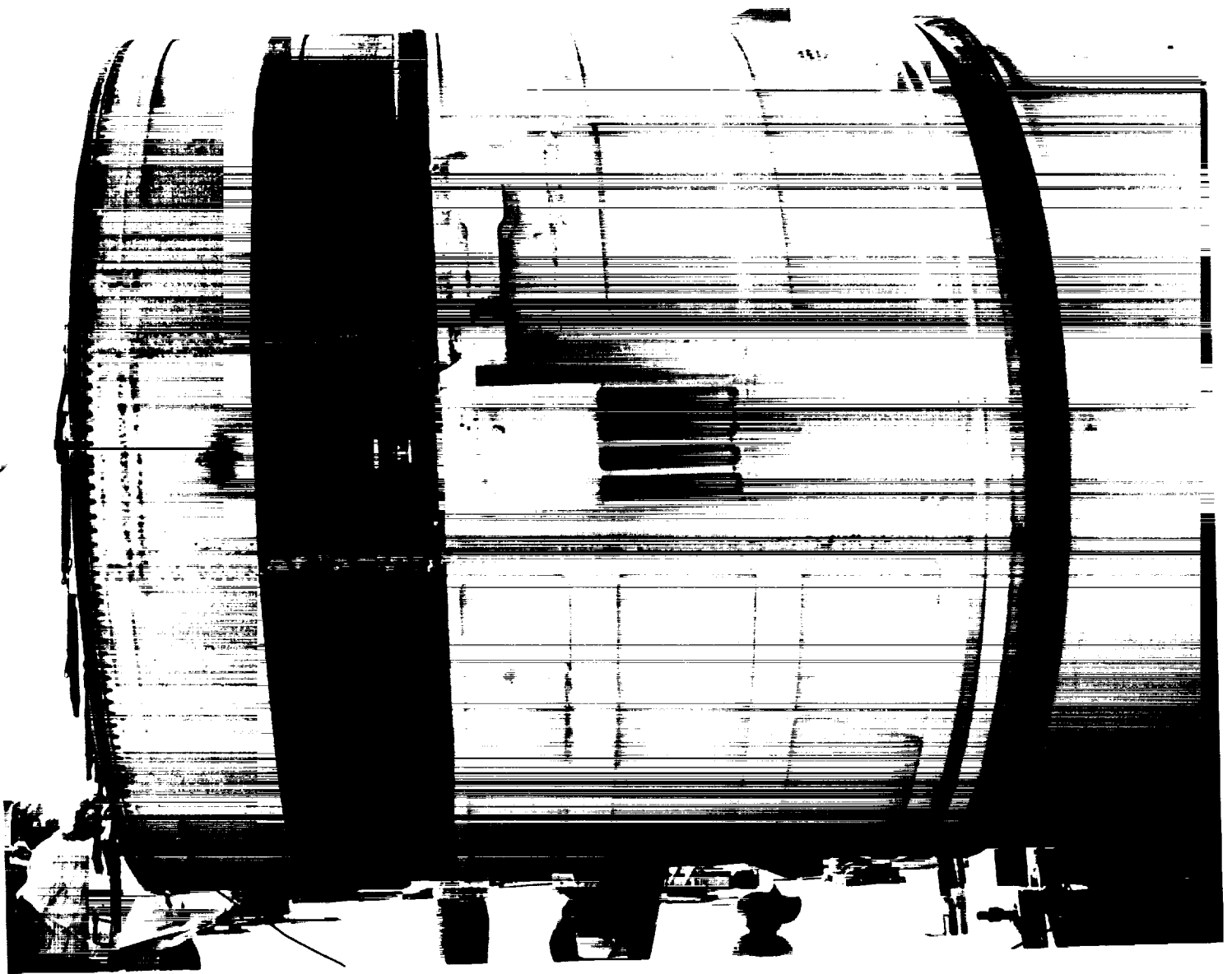


Photo 19 : LH Forward Assembly





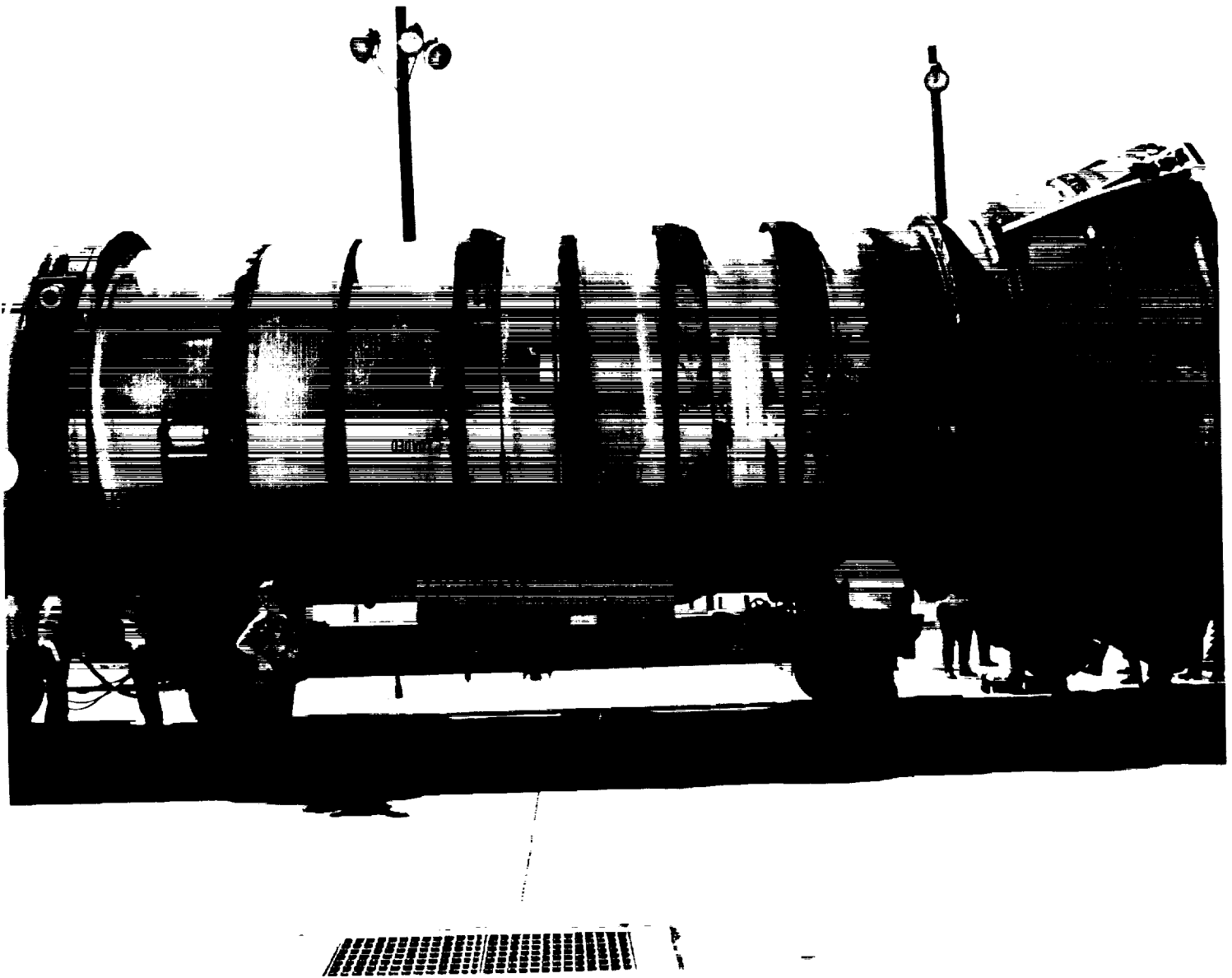


Photo 20 : LH Aft Booster/ Aft Skirt



## 7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-104 (Atlantis) was conducted 14-16 November 1994 at the Dryden Flight Research Center/Edwards Air Force Base on runway 22 and in the Mate/Demate Device. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 148 hits, of which 28 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 50 previous missions of similar configuration (excluding missions STS-23, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger were slightly greater than average (reference Figures 4-7).

The following table breaks down the STS-66 Orbiter debris damage by area:

	<u>HITS &gt; 1"</u>	<u>TOTAL HITS</u>
Lower surface	22	111
Upper surface	2	29
Right side	1	2
Left side	0	0
Right OMS Pod	1	1
Left OMS Pod	2	5
TOTALS	28	148

The Orbiter lower surface sustained a total of 111 hits, of which 22 had a major dimension of 1-inch or larger. The two largest damage sites on the lower surface were located forward of the LO2 ET/ORB umbilical and measured 7.375 inches by 3.75 inches by 0.5 inches and 5.25 inches by 1.25 inches by 0.25 inches. Slumping occurred on two lower surface tiles at the left inboard elevon leading edge near the center hinge location (tiles 193023-033 and -035).

The supply water dump ice deposit on the forward section of the left payload bay door, as observed in the on-orbit video downlink, was still attached after landing and measured approximately 8 inches by 4 inches by 2 inches (IFA STS-66-V-10/IPR 71V-0013: Ice on Supply Water Dump). Shedding ice from this area during reentry is believed to be the cause of the tile damage on the right OMS pod and rudder/speed brake panel. On-orbit photographs taken by the flight crew two days prior to reentry verified no damage was present at that time.

The largest tile damage sites on the orbiter were located on the top of the RH OMS pod forward facing surface measuring 8 inches by 5 inches by 2 inches and on the leading edge of the right rudder/speed brake panel measuring 12 inches by 4 inches by 2 inches. The damage was most likely caused by impacts from supply water dump ice formed while in orbit.

A piece of AFRSI on the leading edge perimeter of side access fuselage door 45 was detached.

No tile damage from micrometeorites or on-orbit debris was identified during the inspection.

No TPS damage was attributed to material from the wheels, tires, or brakes. The tires were in excellent condition after the landing.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned properly and the debris plungers were seated. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly. This was the first flight of the "shuttered" debris retention system. The previously used "plungers" had been replaced during a recent modification. No significant amounts of foam or red purge seal adhered to the LH2 ET/ORB umbilical near the 4-inch flapper valve. No debris was found on the runway beneath the ET/ORB umbilical cavities.

Orbiter windows #3 and #4 exhibited light hazing and streaks. A total of 17 hits were observed on the perimeter tiles of windows #2, 3, 4, and 5 with the largest damage site measuring 1.5 inches by 1 inch by 1 inch at window #2. Tile hits in this area and window streaking have been attributed in the past to impacts from FRCS paper covers and/or paper cover RTV.

A 2 inch by 1 inch by 1 inch thick portion of an aft perimeter tile on window #8 was missing (IFA STS-66-V-15).

The number of tile damage sites on the base heat shield was normal with the majority of the hits occurring near the center of the heat shield. The Dome Mounted Heat Shield (DMHS) closeout blankets on all three SSME's were in good condition with SSME #1 exhibiting a torn blanket from 4 to 6 o'clock position and fraying at the 12 o'clock position. The aft quarter of a body flap stub tile (395018-163 S83055) was missing from the +Z side of the body flap below and outboard of SSME #2 and was the black tile fragment observed during launch film reviews. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged.

This was the first use of a refurbished drag chute. All drag chute hardware was recovered and showed no signs of abnormal operation. Two 6 inch by 6 inch pieces of black Teflon fabric used in the packing of the chute to prevent abrasions were also recovered on the runway.

Runway 22 had been swept/inspected by Air Force personnel prior to landing and all potentially damaging debris was removed. A post landing walkdown of the runway was performed immediately after landing. No Shuttle flight hardware was found on the runway.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was slightly greater than average when compared to previous missions (Figures 8-9). The type of TPS damage was typical and not attributable to any single debris source.

Orbiter Post Launch Debris Anomalies are listed in Section 9.

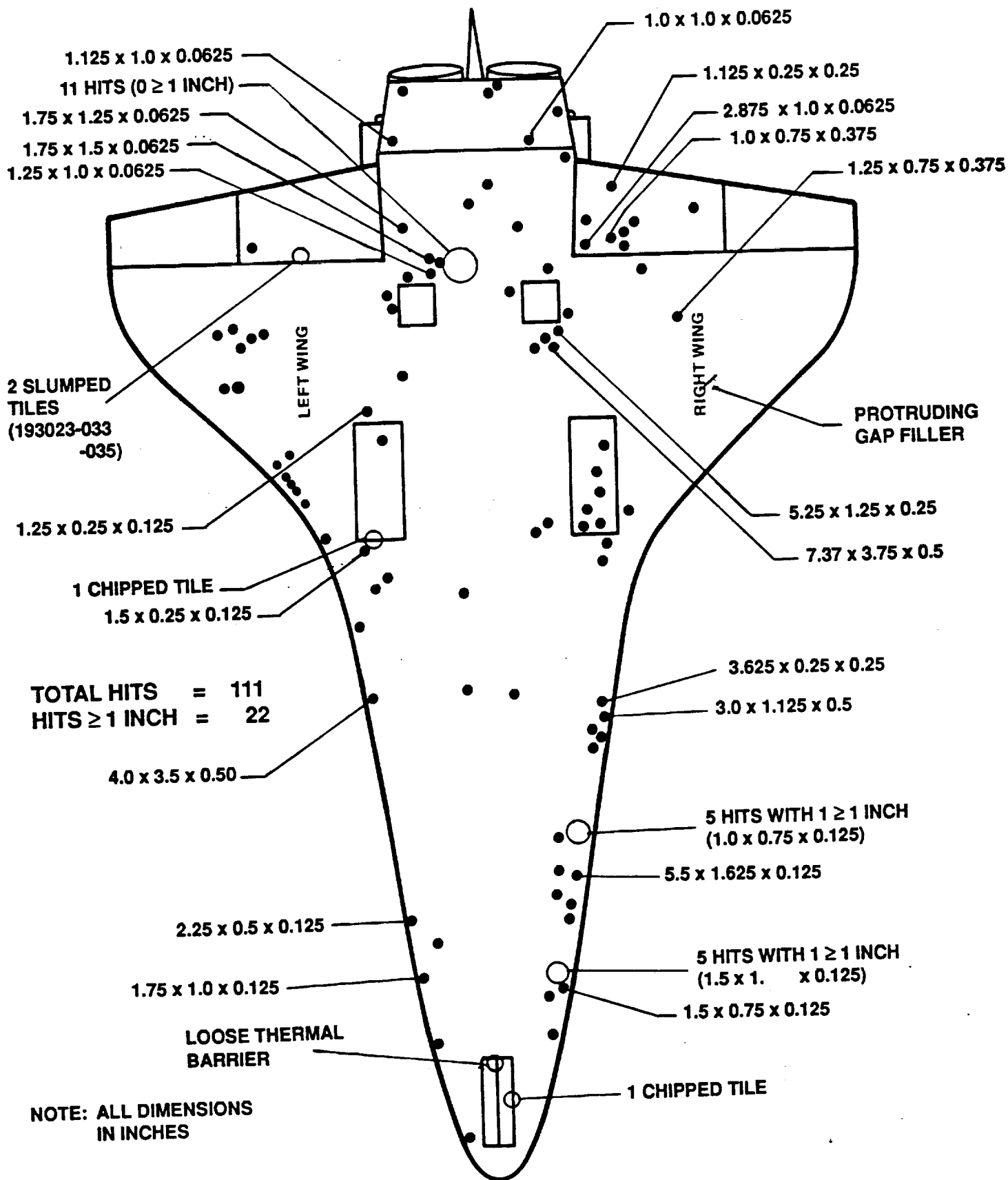
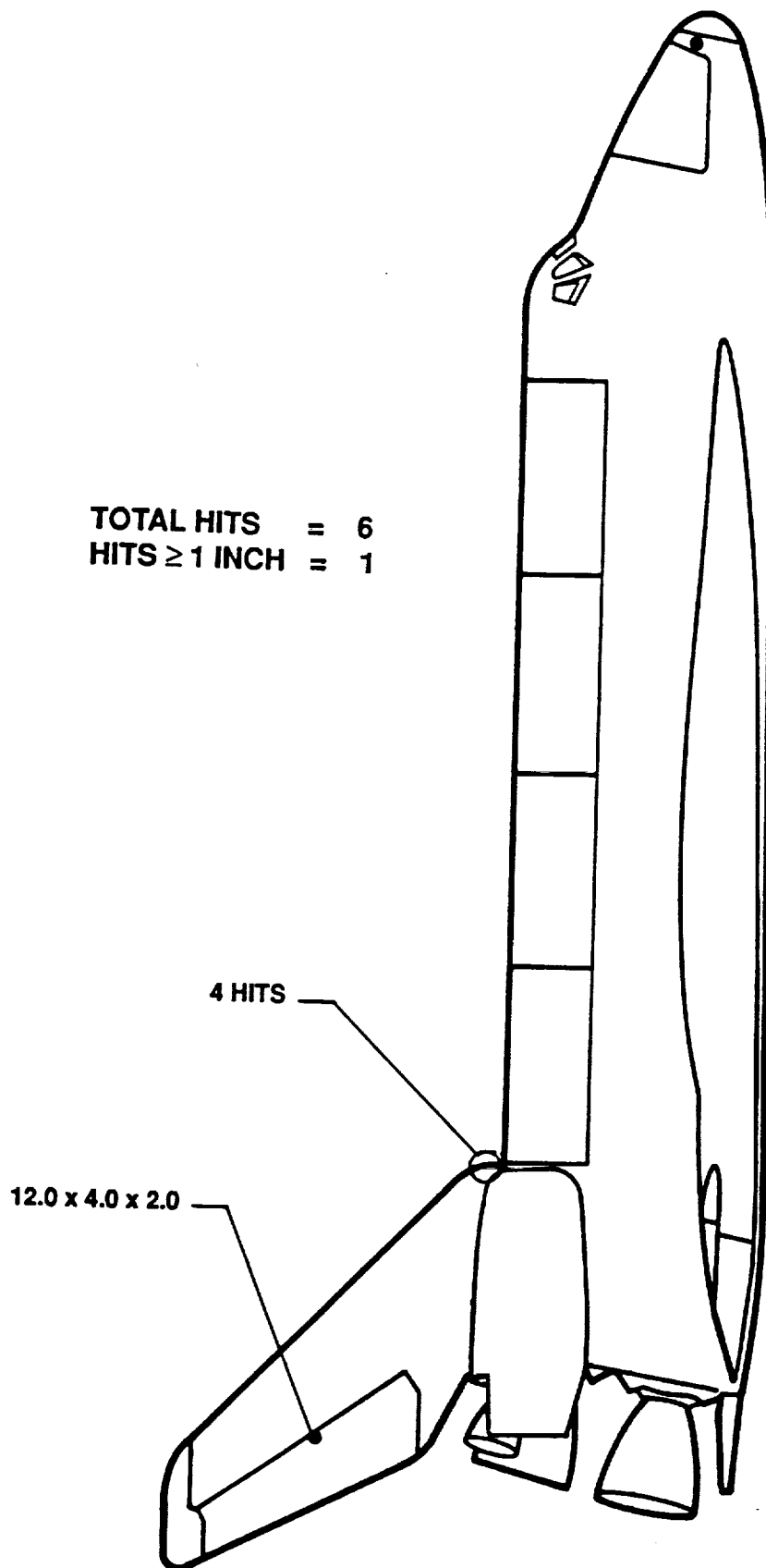
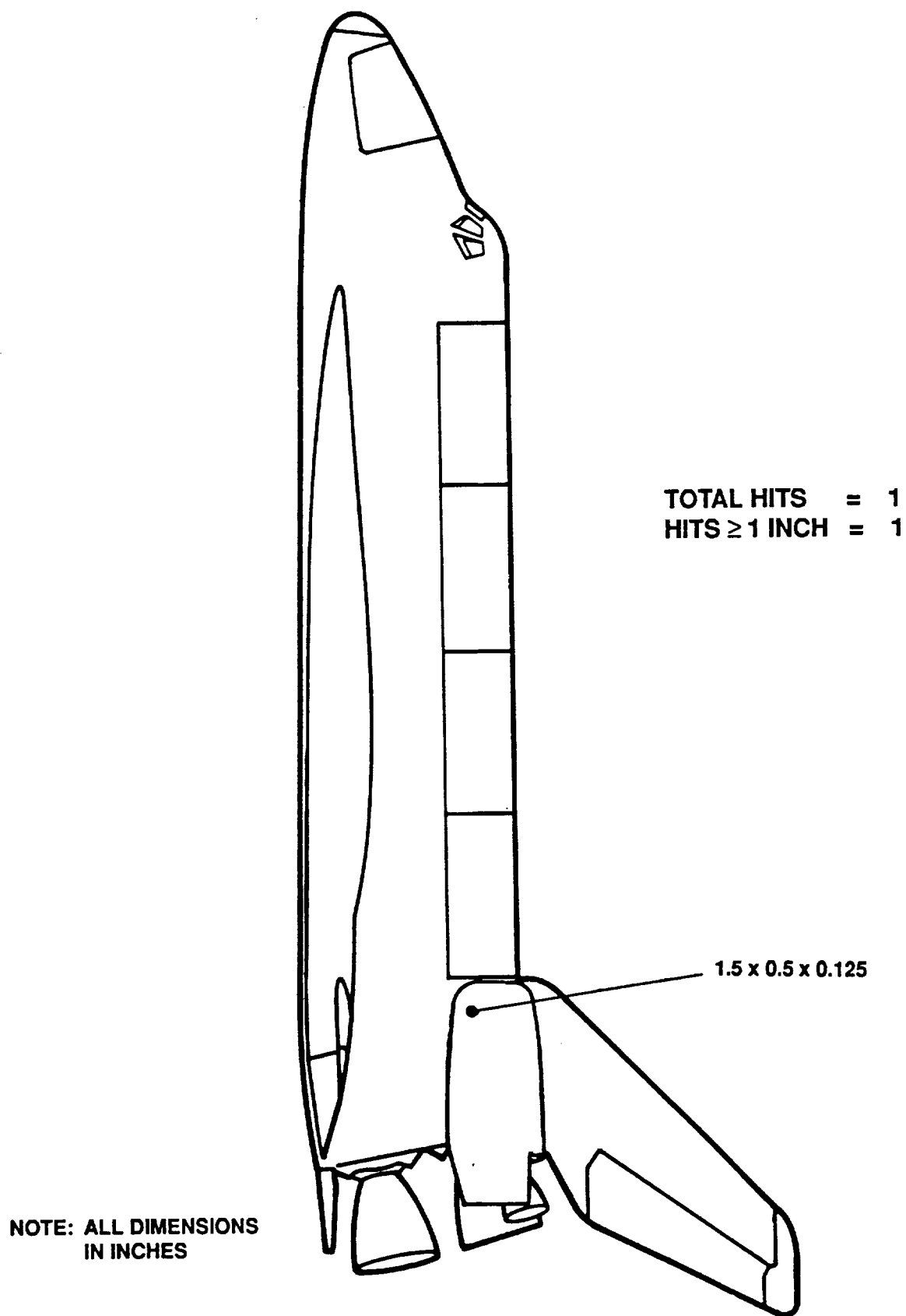


Figure 4 : Orbiter Lower Surface Debris Map



**NOTE: ALL DIMENSIONS  
IN INCHES**

**Figure 5 : Orbiter Right Side Debris Map**



**Figure 6 : Orbiter Left Side Debris Map**

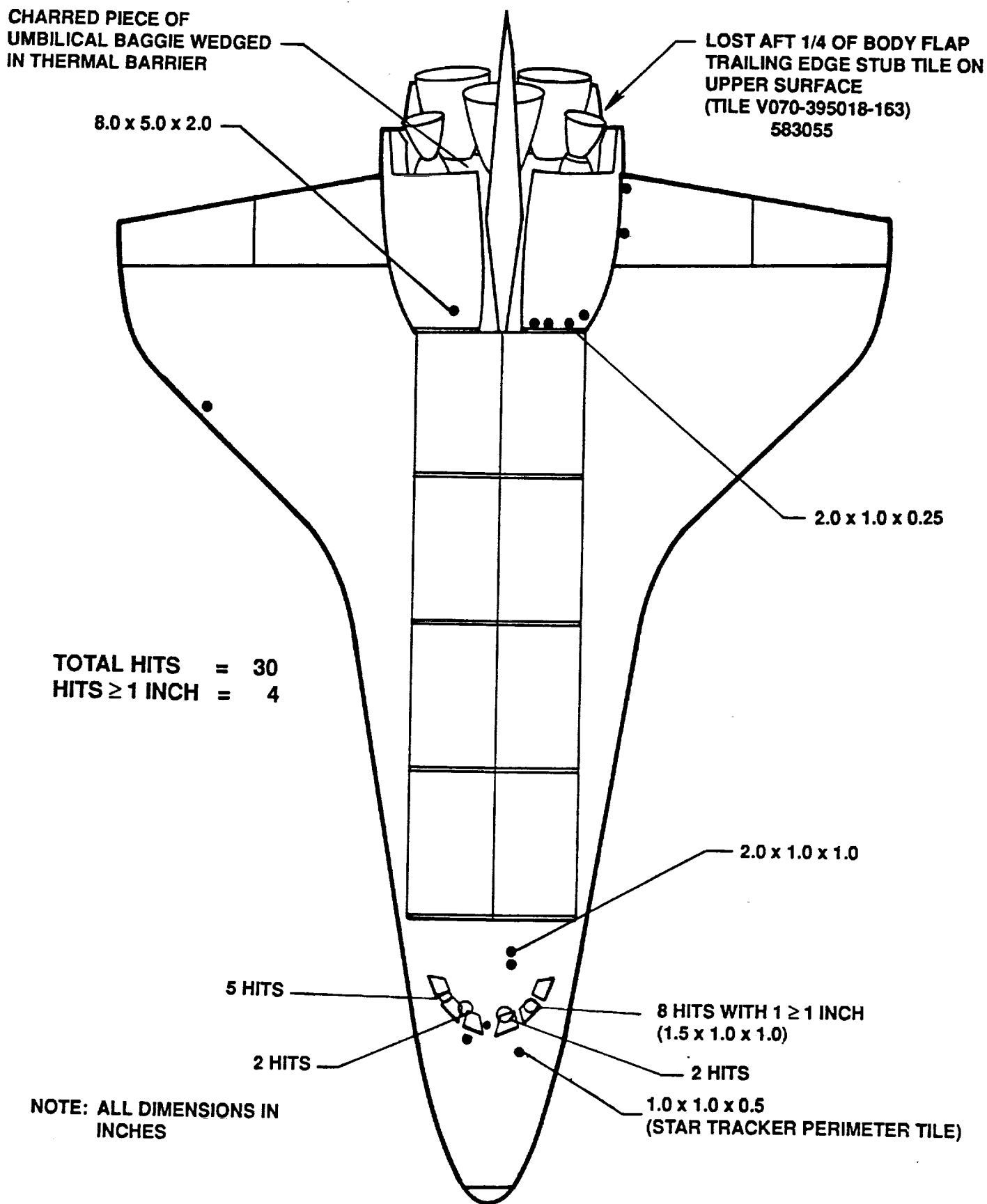


Figure 7 : Orbiter Upper Surface Debris Map



	LOWER SURFACE		ENTIRE VEHICLE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	15	80	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
AVERAGE	14.0	90.1	21.2	131.2
SIGMA	7.2	43.6	10.1	56.0
STS-66	22	111	28	148

MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS  
SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCE

**Figure 8 : Orbiter Post Flight Debris Damage Summary**

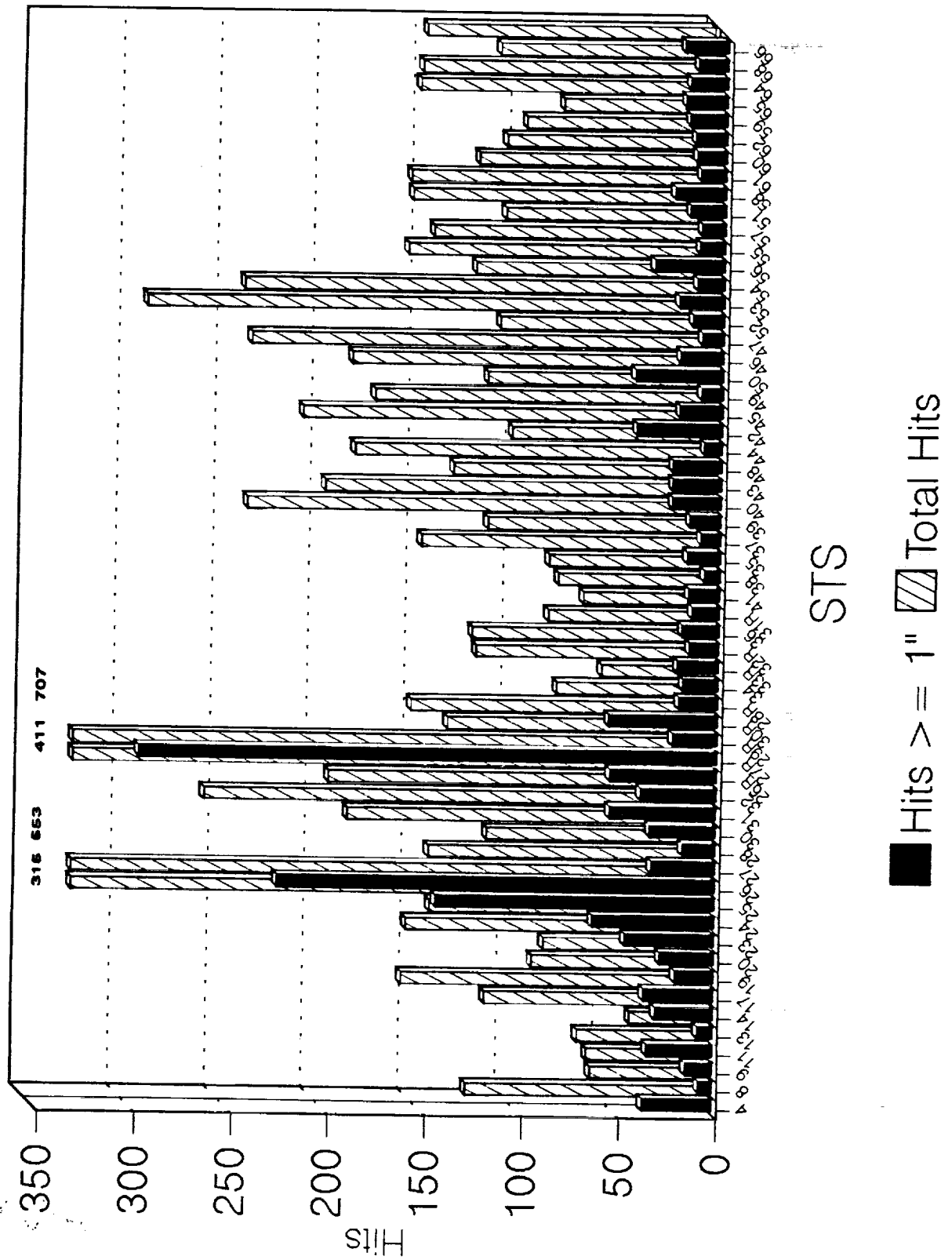


Figure 9 : Orbiter Debris Damage Comparison Chart

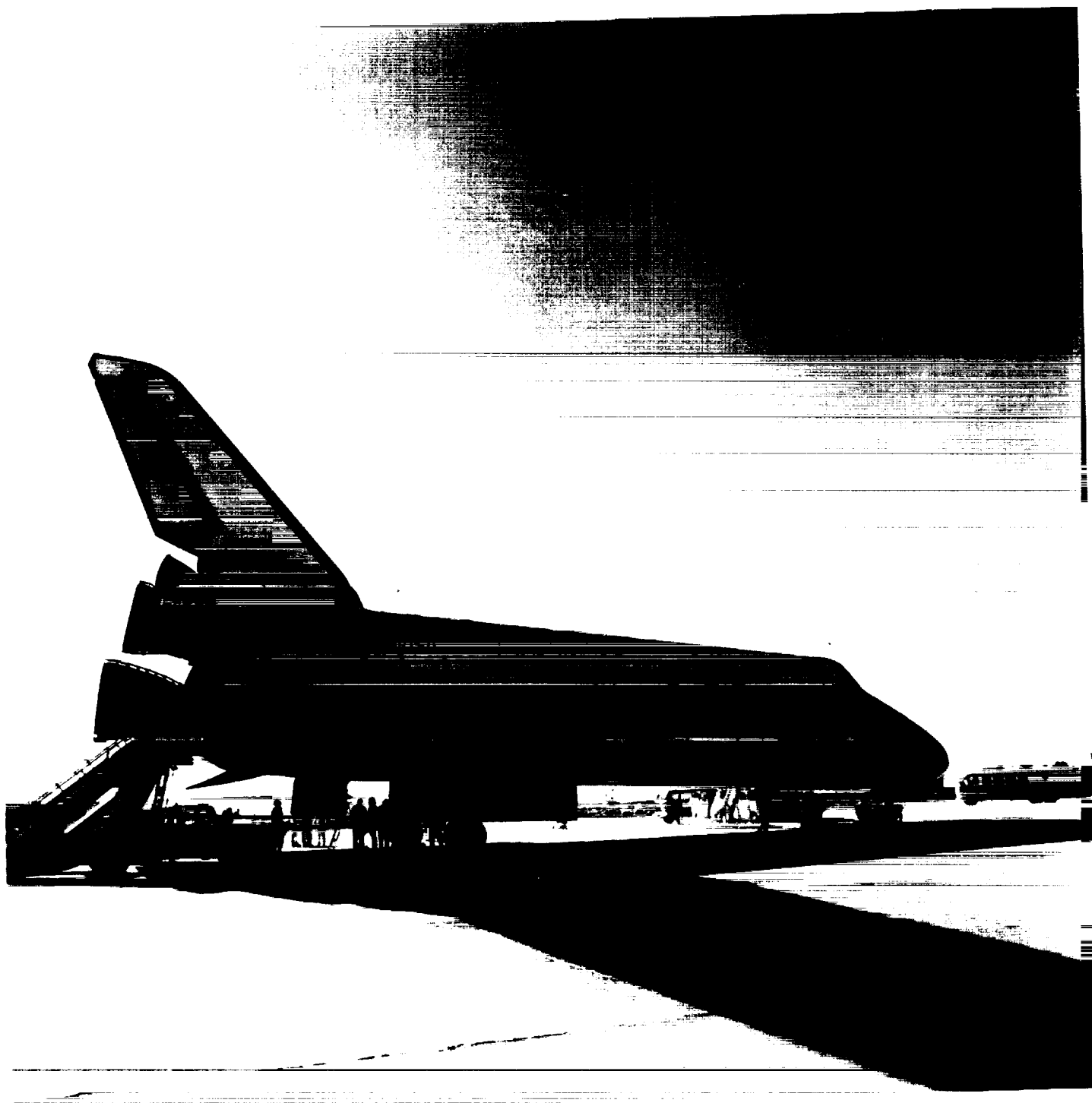


Photo 21 : Overall View of Orbiter Right Side





**Photo 22 : Overall View of Orbiter Left Side**  
Note ice still attached to left payload bay door (arrow)

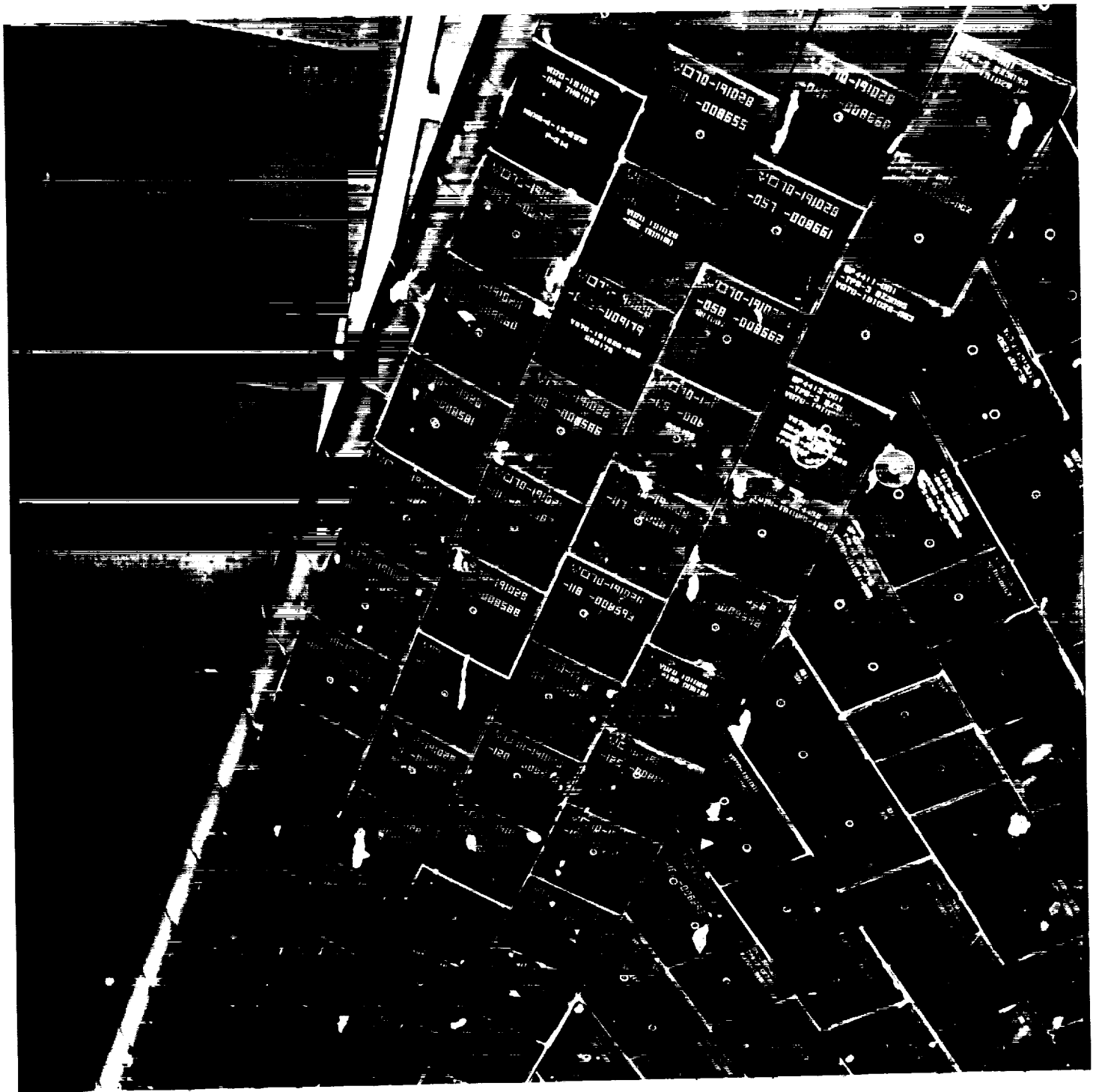




Photo 23 : Overall View of Orbiter Nose/Windows



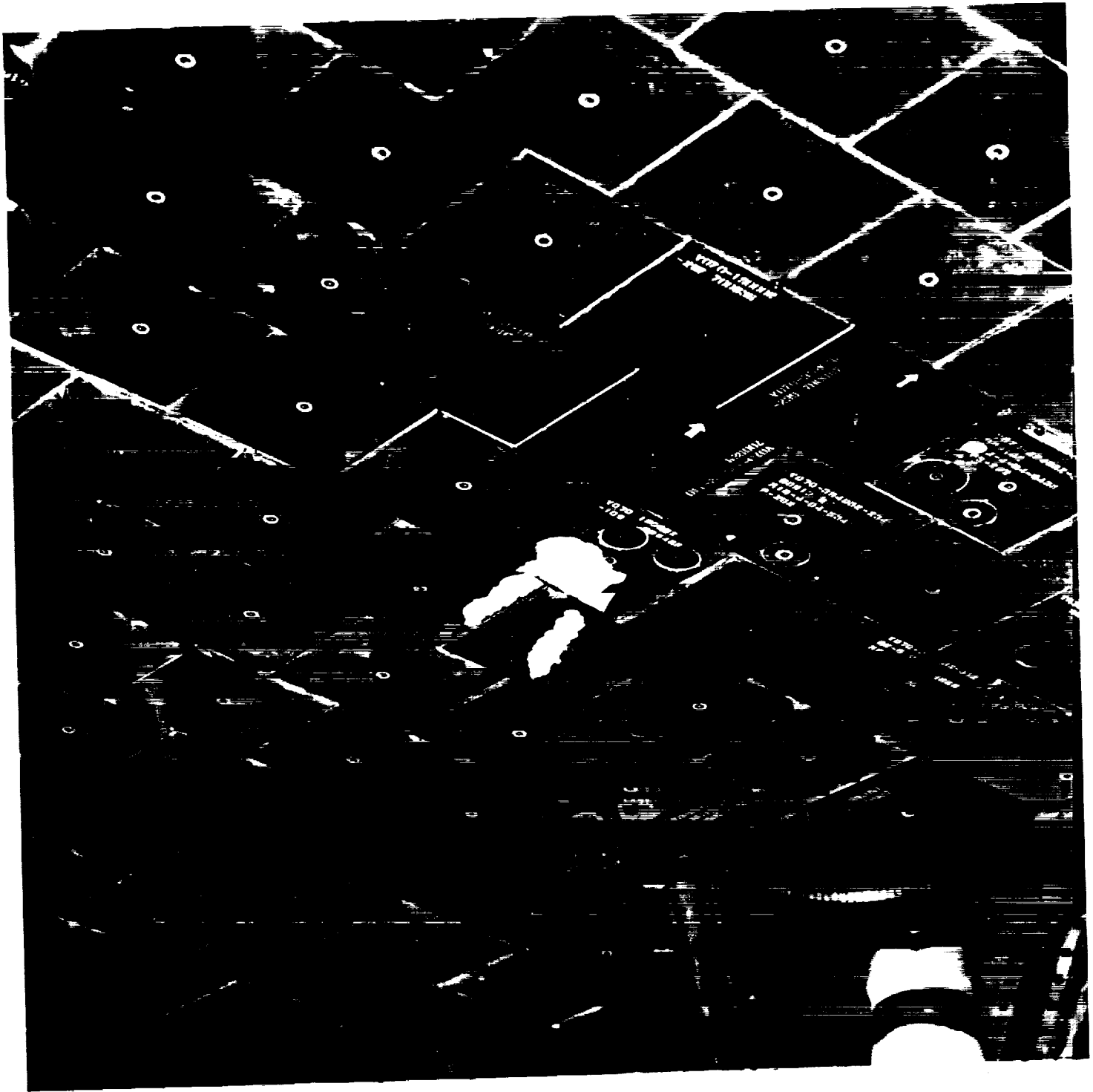




**Photo 24 : Lower Surface Tile Damage**

The Orbiter lower surface sustained a total of 111 hits, of which 22 had a major dimension of 1-inch or larger. This view includes the lower right side/chine area.





**Photo 25 : Lower Surface Tile Damage**

The two largest damage sites on the lower surface were located forward of the LO2 ET/ORB umbilical and measured 7.375 inches by 3.75 inches by 0.5 inches and 5.25 inches by 1.25 inches by 0.25 inches.

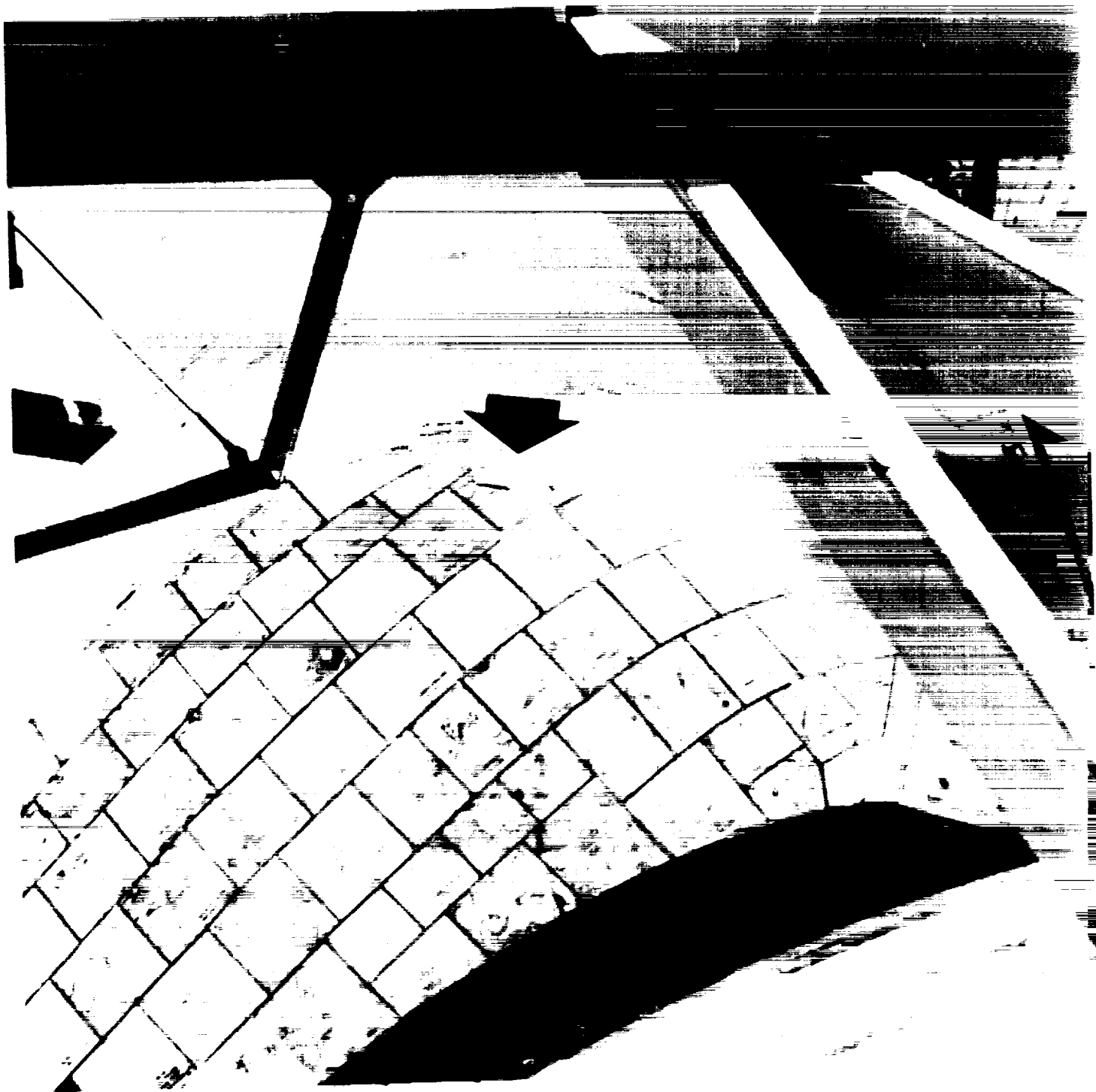




**Photo 26 : Ice Attached to Left Payload Bay Door**

A portion of the supply water dump ice deposit on the forward section of the left payload bay door was still attached after landing and measured approximately 8 inches by 4 inches by 2 inches



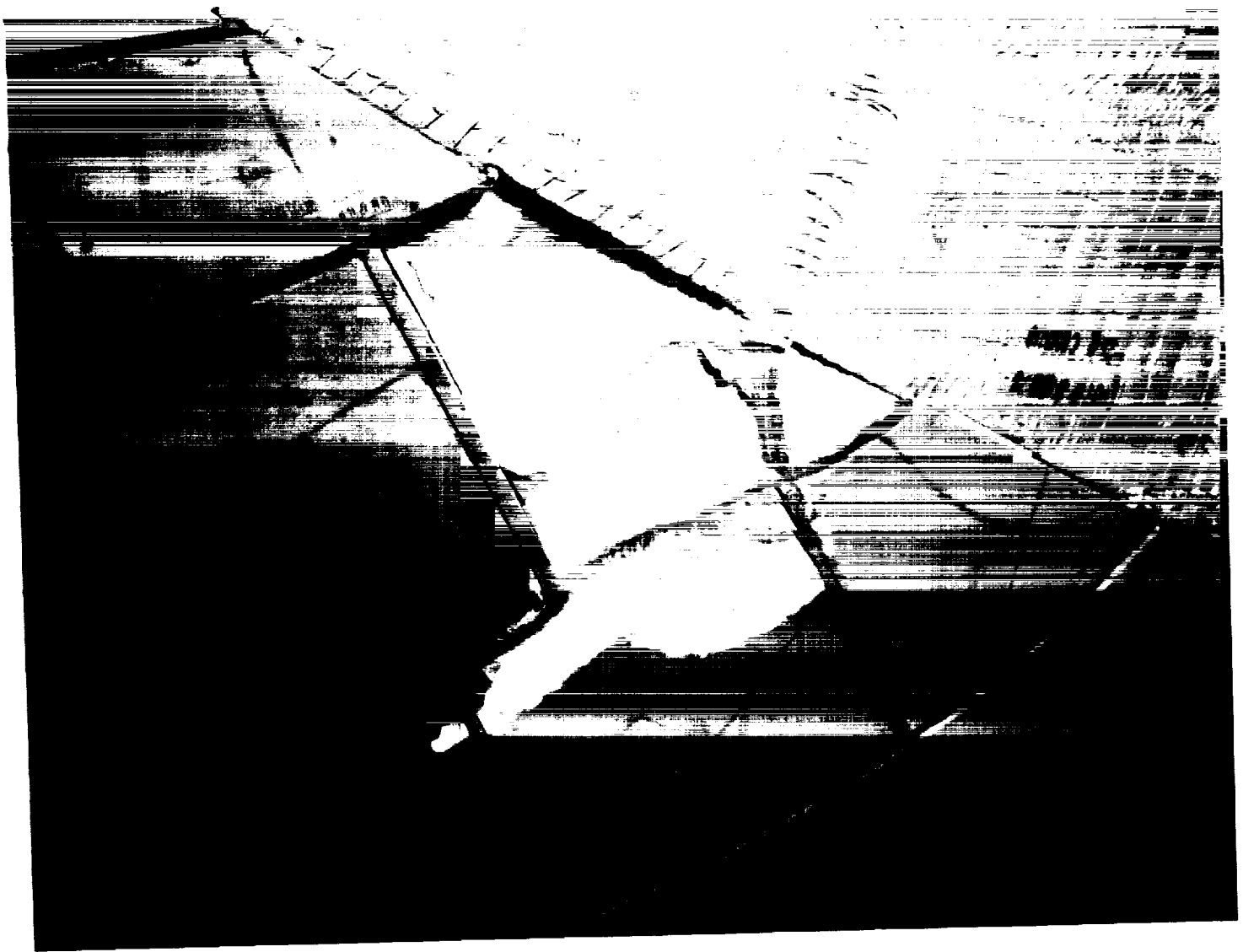


**Photo 27 : RH OMS Pod Tile Damage**

Pieces of ice from the payload bay door falling aft during reentry are believed to be the cause of the tile damage on the right OMS pod







**Photo 28 : RH OMS Pod Tile Damage**

One of the largest tile damage sites on the orbiter was located on the RH OMS pod forward facing surface and measured 8 inches by 5 inches by 2 inches. The damage was most likely caused by impacts from supply water dump ice formed while in orbit.





**Photo 29 : On-Orbit View of RH OMS Pod**

On-orbit photograph taken by the flight crew two days prior to reentry verified no damage to RH OMS pod tiles was present at that time

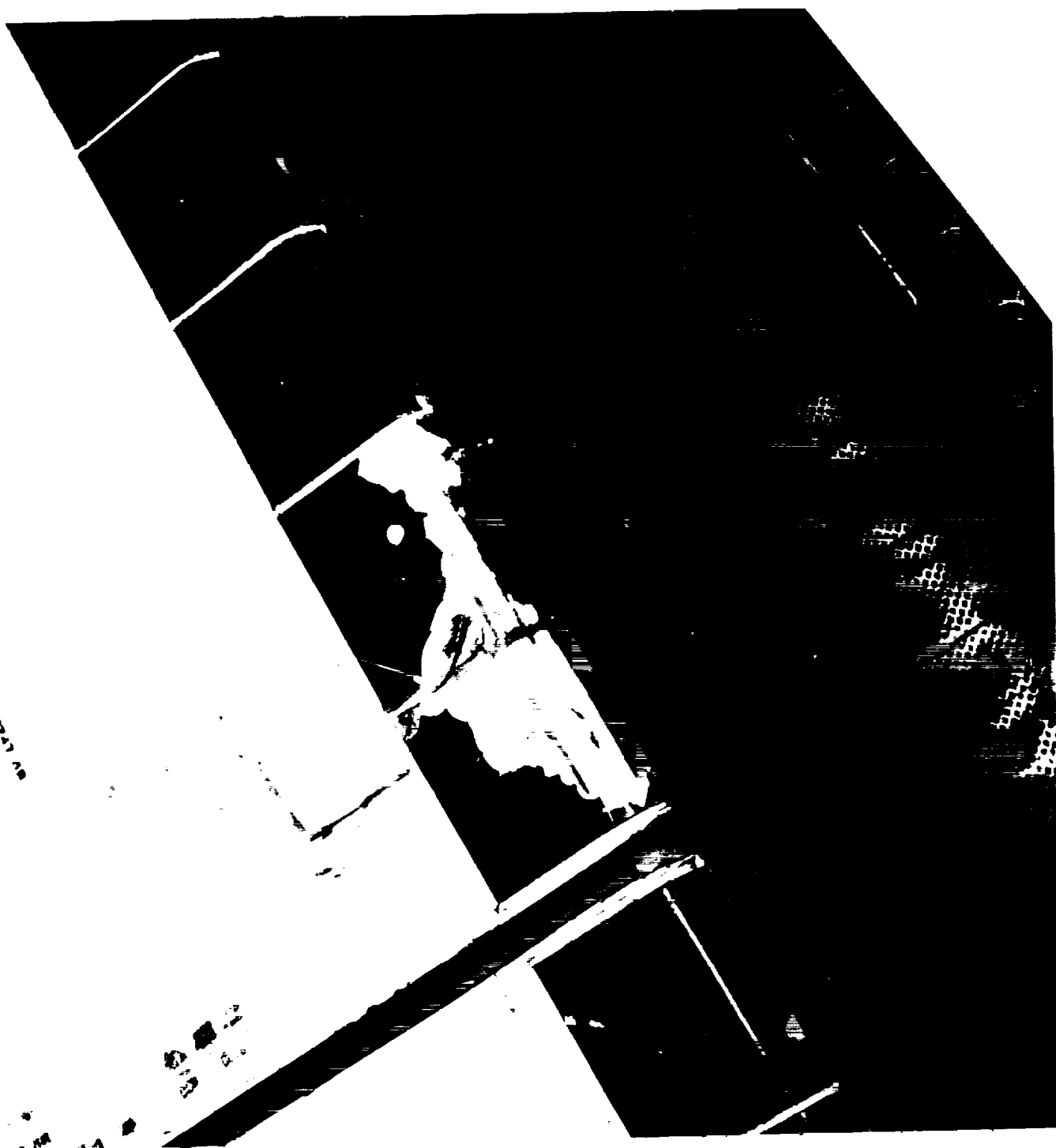




**Photo 30 : Rudder/Speed Brake Tile Damage**

Pieces of ice from the payload bay door falling aft during reentry is believed to be the cause of the tile damage on the right rudder/speed brake panel





**Photo 31 : Rudder/Speed Brake Tile Damage**

One of the largest tile damage sites on the orbiter was located on the leading edge of the right rudder/speed brake panel and measured 12 inches by 4 inches by 2 inches. The damage was most likely caused by impacts from supply water dump ice formed while in orbit.





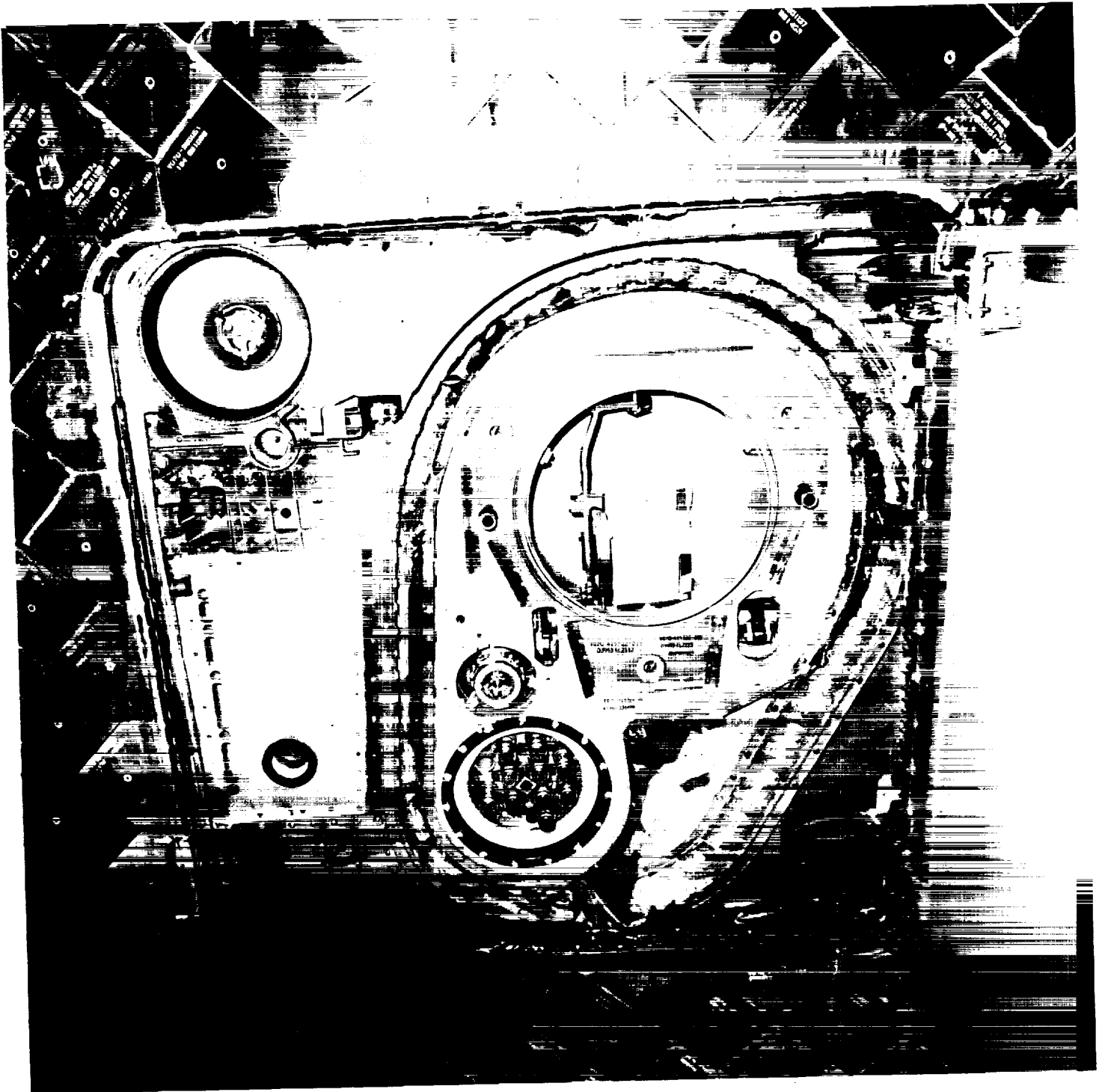


Photo 32 : LO2 ET/ORB Umbilical



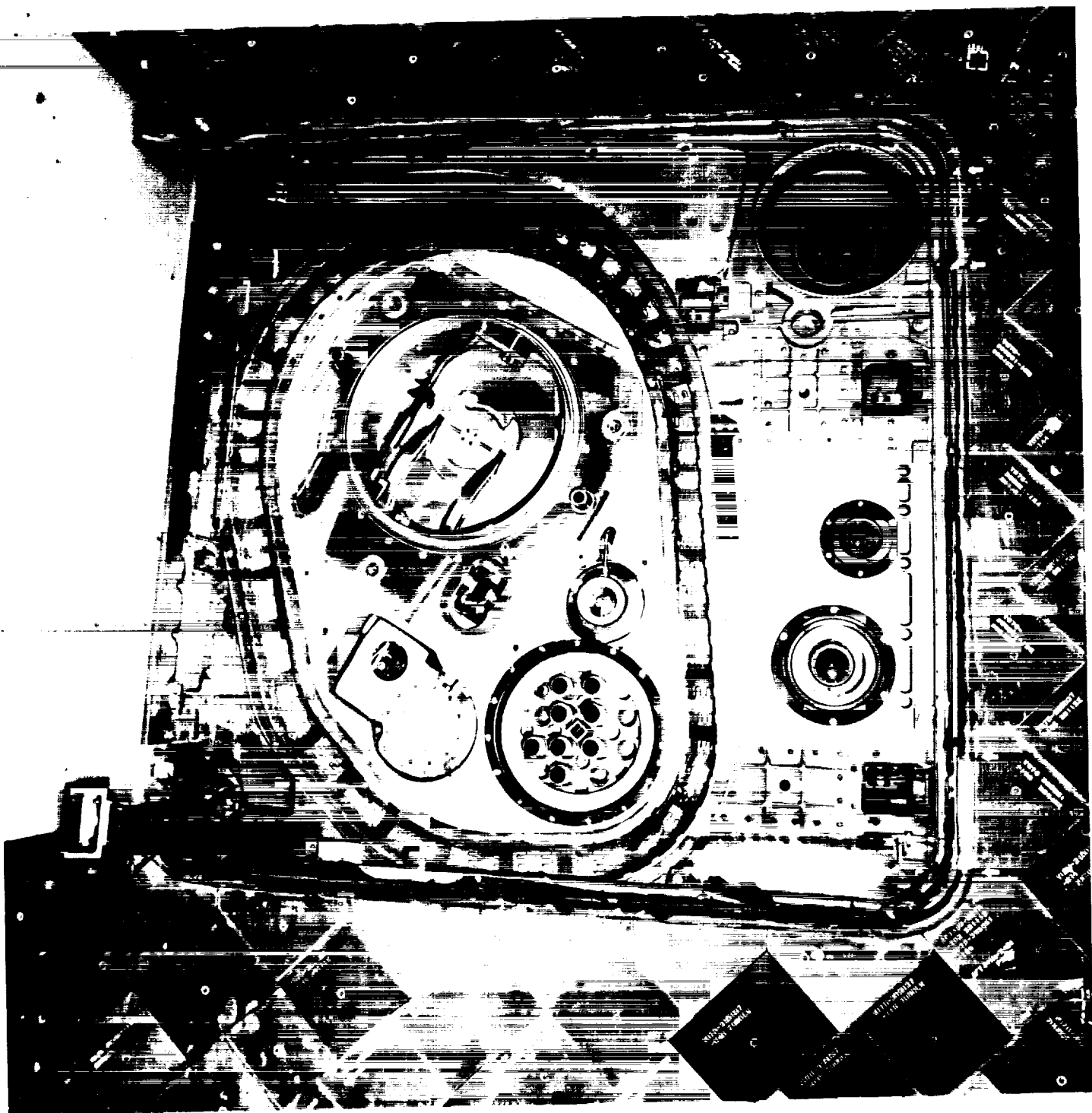


Photo 33 : LH2 ET/ORB Umbilical



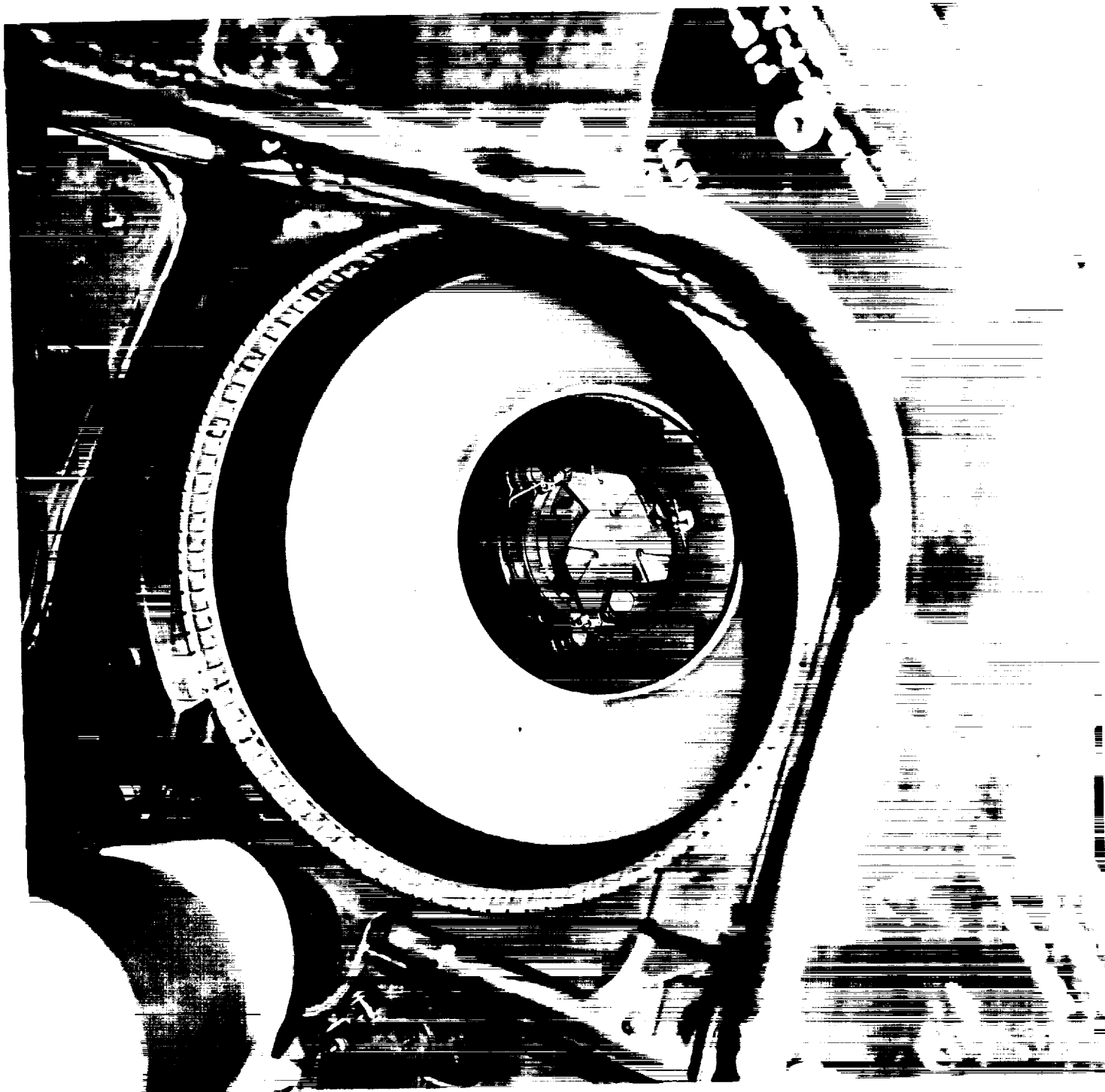


Photo 34 : First Flight of "Shuttered" Debris Retention System





**Photo 35 : Body Flap Stub Tile Damage**

The aft quarter of a body flap stub tile was missing from the +Z side of the body flap below and outboard of SSME #2. The black tile fragment had shaken loose during SSME ignition and was observed falling into the SSME exhaust hole during the launch film review.





## **9.0 DEBRIS SAMPLE LAB REPORTS**

A total of eight samples were obtained from OV-104 Atlantis during the STS-66 post landing debris assessment at Dryden Flight Research Center, California. The submitted samples consisted of 8 wipes from Orbiter windows #1-8. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves both the placing and the correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries. Also included in this report are the results of a recent Orbiter window debris sample from the STS-68 mission.

### **9.1 ORBITER WINDOWS**

Samples from the Orbiter windows indicated exposure to facility environment, SRB BSM exhaust (metallic particulate), landing site materials (earth minerals), Orbiter Thermal Protection System (tile, tile repair, RTV and glass insulation), paints and primer from various sources. Paint particulate continues to be present in a variety of colors: black, white, red, blue, green, and yellow. The yellow paint particulate contained lead, which is typically found in facility/GSE paint. There was no apparent vehicle damage related to these residuals.

### **9.2 STS-66 ORGANIC ANALYSIS**

The results of the STS-66 organic analysis are shown in Figure 10. Identified materials include those associated with window covers (plastic polymers), RTV from RCS thruster nozzle cover adhesive and Orbiter Thermal Protection System, and paint from various sources. There was no apparent vehicle damage related to these residuals.

### **9.3 STS-68 WINDOW DEBRIS SAMPLE**

After Orbiter OV-105 (Endeavour) ferry flight to KSC/post-flight processing and during OPF processing for the next mission, debris material was found between window #2, #3, and #4 frame and glass pane. The recovered material appeared to have burned edges. This material was examined/tested at the MAB and found to be a paper material containing an acrylic based paint and having a polyester coating. The paper visually compared to the red and white checkered 'butcher paper' used on forward RCS nozzles to prevent moisture intrusion. Direct comparative testing is in work. Motion picture cameras previously mounted in the pilot's window on some of the launches early in the program had documented FRCS paper cover impacts on the forward facing windows during ascent. No apparent vehicle debris damage was caused by this debris.

### **9.4 NEW FINDINGS**

This set of post-flight debris residual samples led to one new finding, which was obtained in the STS-68 window debris sample. The material was identified as 'butcher paper' used for moisture protection on the Reaction Control System thruster nozzles. This debris sample showed the Orbiter windows continue to be an area that collects various forms of debris and is consequently a constant source of post flight samples. The recovered paper material did not appear to be related to any debris damage.

STS	Sample Location			
	Windows	Wing RCC	Lower Tile Surface	Umbilical
66	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer			
68	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)	ET GOX Vent Seal land area and GOX Seal Sample- Metallic Particulate WINDOW DEBRIS SAMPLE- 'Butc Paper'
64	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer			
65	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)	
59	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-Building insulation, wipe cloth Earth minerals - (Landing site) Organics- Plastic polymers, sealant RTV-RCS nozzle thruster cover Paint and primer			
62	Metallics - Fac Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-Building insulation, wipe cloth Earth minerals - (Landing site) Organics- Plastic polymers, sealant RTV-RCS nozzle thruster cover Paint and primer			

Figure 10 : Orbiter Post Landing Microchemical Sample Results

## **10.0 POST LAUNCH ANOMALIES**

Based on the debris walkdowns and film/video review, twelve post launch anomalies, including three In-Flight Anomalies (IFA's), were observed on the STS-66 mission.

### **10.1 LAUNCH PAD/SHUTTLE LANDING FACILITY**

1. Numerous open and damaged access doors and cable tray covers.
2. A 4-foot by 5-foot Herculite cover lay on the FSS 195 foot level grating.

### **10.2 SOLID ROCKET BOOSTERS**

1. The RH frustum was missing no TPS but had 50 debonds over fasteners and 2 debonds over acreage. Since the number of debonds was greater than the frustum history average of 25 debonds, a representative set of the MSA-2 debonds were analyzed by MSFC for possible material or processing anomalies (IFA: MSA-2 did not adhere to painted surfaces adjacent to PR 1422-sealant-over-fastener debonds. The problem was traced to an MSA-2 spray pump problem).
2. A 2-inch debond occurred at the 145 degree location in the RH forward segment factory joint.
3. One MSA-2 debond occurred near the Right aft skirt -Y axis at the XB-1860 ring frame. A 2-inch diameter MSA-2 divot was present near the -Y axis at the XB-1894 ring frame.
4. The LH frustum was missing no TPS but had 39 MSA-2 debonds over fasteners.

### **10.3 EXTERNAL TANK**

1. Two TPS divots were observed on the LO2 tank at or near the LO2 pressurization line ramps: one 4-inch divot at approximately XT-514; one 9-inch divot at approximately XT-676.
2. Three stringer head divots were observed on the intertank acreage: one 14-inch divot just forward of the -Y bipod spindle housing closeout; one 17-inch divot with exposed substrate on the +Z axis forward of the bipods; and one 24-inch divot with exposed substrate on the +Z axis forward of the bipods. (This type of divot had been the subject of an IFA previously. Manufacturing procedures at the factory were modified, effective on ET-74, to reduce the potential for TPS damage during intertank assembly).
3. The lightning contact strip across the forward part of the LO2 ET/ORB umbilical was missing and observed drifting near the umbilical area.

### **10.4 ORBITER**

1. A 2-inch by 1-inch by 1-inch portion of an aft perimeter tile on window #8 was missing. (IFA STS-66-V-15).
2. The supply water dump ice deposit on the forward section of the left payload bay door, as observed in the on-orbit video downlink, was still attached after landing and measured approximately 8 inches by 4 inches by 2 inches. (IFA STS-66-V-10/IPR 71V-0013: Ice on Supply Water Dump). Shedding ice from this area during reentry most likely caused the tile damage on the right OMS pod and rudder/speed brake.
3. The largest tile damage sites on the orbiter were located on the top of the RH OMS pod forward facing surface measuring 8 inches by 5 inches by 2 inches and on the leading edge of the right rudder/speed brake panel measuring 12 inches by 4 inches by 2 inches. The damage was most likely caused by impacts from supply water dump ice formed while in orbit.



## **APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY**



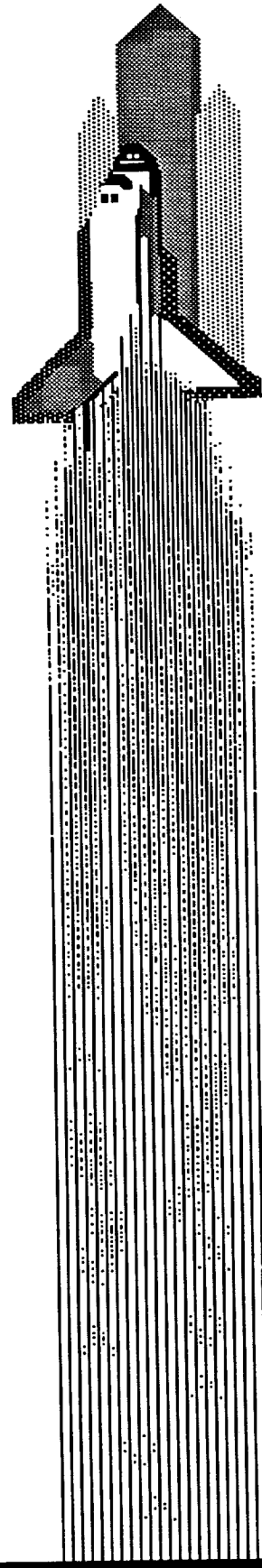
# **Space Shuttle**

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Photographic and Television  
Analysis Project

## **STS-66 Summary of Significant Events**

December 23, 1994



# Space Shuttle Photographic and Television Analysis Project

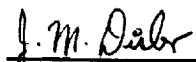
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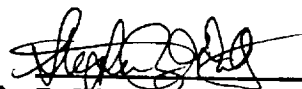
## STS-66 Summary of Significant Events

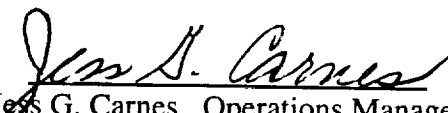
Project Work Order - SN-52V

### Approved By

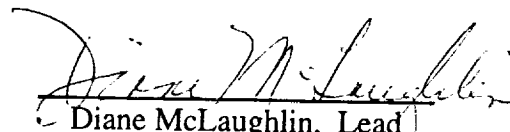
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# **1. OV-104 STS-66 FILM/VIDEO SCREENING AND TIMING**

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## **1. OV-104 STS-66 FILM/VIDEO SCREENING AND TIMING SUMMARY**

### **1.1 SCREENING ACTIVITIES**

#### **1.1.1 Launch**

Atlantis (OV-104) launched on mission STS-66 from Pad B at 16:59:43.015 Coordinated Universal Time (UTC) on November 3, 1994 (day 307) as seen on camera E-9. Solid rocket booster (SRB) separation occurred at 17:01:47.697 UTC as seen on camera ET-207.

On launch day, 23 videos were screened. Following launch day, 53 films were reviewed.

No anomalies were observed during launch.

DTO-312 photography of the STS-66 external tank (after separation) was acquired using a 35 mm Nikon camera equipped with a 300 mm lens and a 2X extender (Method 3). Twenty-two exposures from Magazine 01 were received and screened. In addition, the crew obtained video footage of the ET after separation. Results from this screening process can be found in Section 2.4.1.

#### **1.1.2 On-Orbit**

No on-orbit events required PTAP support.

#### **1.1.3 Landing**

The first landing opportunity on the morning of November 14 was waived off due to weather constraints at the Kennedy Space Center.

Atlantis landed on runway 22 at Edwards Air Force Base on November 14, 1994 (day 318). Six videos of the Orbiter's approach and landing were received. NASA Select, a composite created from the available landing views, was also screened.

<b>Event Description</b>	<b>Timing</b>	<b>Camera</b>
Landing gear doors opened	15:33:22.310 UTC	LRO-1
Left main gear touchdown	15:33:45.031 UTC	LRO-1
Right main gear touchdown	15:33:45.064 UTC	LRO-1
Nose wheel touchdown	15:33:55.608 UTC	LRO-1
Wheel stop	15:33:35.348 UTC	LRO-1

**Table 1.1.3** Landing Event Times

Two dark pieces of debris, thought to be related to the drag chute apparatus, were noted during the rollout. Two dark pieces of debris were seen near the drag chute during

## 1. OV-104 STS-66 FILM/VIDEO SCREENING AND TIMING

deployment. See Section 2.6.2 for event details. Consultation with engineers suggested that Teflon coverings (recently added to reduce abrasion) as the most likely source of the debris. Landing films will be reviewed for more detail when they are received.

A white protuberance was seen on the cargo bay door just aft of the overhead window on the port side during the walkaround. TPS engineers have confirmed that this object was ice.

The deployment of the drag chute appeared as expected. See Figure 2.6.3 for event times.

The following items were noted during the post landing walk around: TPS damage to the starboard side of the rudder speed brake, slight TPS damage to the right OMS pod, slight tile damage on the underside of the right wing, and slight TPS damage on the base heat shield between the SSMEs. The drag chute housing and the tires appeared to be in satisfactory condition.

## 1. OV-104 STS-66 FILM/VIDEO SCREENING AND TIMING

### 1.2

All videos except ET-208 and KTV-7B had timing and film cameras E-1, E-2, E-3, E-4, E-5, E-6, E-7, E-8, E-9, E-10, E-11, E-12, E-14, E-15, E-17, E-18, E-19, E-20, E-25, E-26, E-52, E-54, E-57, E-59, E-79, E-222 and E-224 had in-frame alphanumeric timing. These videos and films were used to time specific mission events during the initial screening. The following events were timed from film cameras:

Camera	Frame	Comments	Timing (UTC)
E-213		Large light colored debris near RSRB aft skirt	307:17:00:14.123
		Same debris causes flare in SSME plume	307:17:00:14.238
E-220		Debris fell along SRB plume	307:17:00:49.965
		Debris fell along SRB plume	307:17:00:53.218
		Debris fell along SRB plume	307:17:00:53.248
		Debris fell along SRB plume	307:17:00:53.743
		Debris fell along SRB plume	307:17:00:55.512
		Debris fell along SRB plume	307:17:00:58.909
		Debris fell along SRB plume	307:17:01:04.412
E-207		Recirculation start	307:17:01:18.254
		Recirculation stop	307:17:01:25.515
		SRB Separation	307:17:01:47.674

**Table 1.2** Film Camera Timing Events

## **2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS**

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### **2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS**

#### **2.1 DEBRIS**

##### **2.1.1 Debris near the Time of SSME Ignition**

##### **2.1.1.1 LH2 and LO2 Tail Service Mast (TSM) T- 0 Umbilical Disconnect Debris** (Cameras E-17, E-18, E-19, E-20, E-76, E-77, OTV-149, OTV-150, OTV-170, OTV-171)

Normal ice debris was noted falling from the LH2 and LO2 TSM T-0 umbilical disconnect areas at SSME ignition through liftoff. None of the debris was observed to strike the vehicle. No follow-up action was requested.

##### **2.1.1.2 LH2 and LO2 ET/Orbiter Umbilical Disconnect Debris** (Cameras E-4, E-5, E-6, E-16, E-25, E-26, E-30, E-31, E-34, E-35, E-40, E-52, E-54, E-57, E-65, E-79, OTV-109, OTV-154, OTV-163)

Normal ice debris was noted falling from the LH2 and LO2 ET/Orbiter umbilical disconnect areas at SSME ignition through liftoff. Multiple pieces of light colored debris (probably ice) were seen striking the umbilical sill and the electric cable tray during SSME startup (as seen on OTV-109). No damage to the SLV was apparent in either case.

##### **2.1.1.3 Rectangular Debris Between Body Flap and SSME #2** (Cameras E-5, E-18)

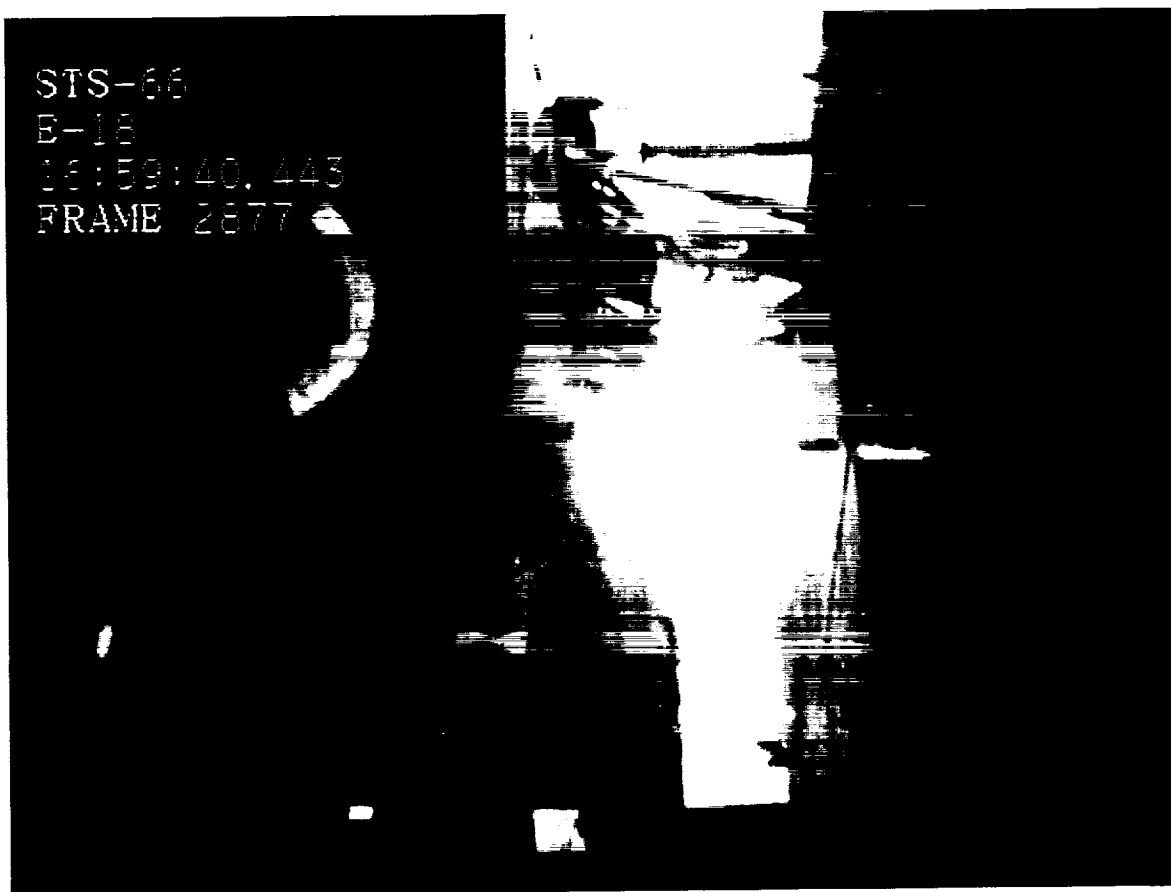
A rectangular-shaped piece of debris, possibly a tile fragment, was seen near the body flap at T-2.782 seconds. The debris, light on one side and dark on the other, was first seen tumbling between the body flap and SSME #2. (See Figure 2.1.1.3). The origin of the debris could not be determined.





## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

---



**Figure 2.1.1.3 Rectangular Debris Near Body Flap**

A rectangular piece of debris is seen passing in front of SSME #2 just prior to liftoff on camera E-18. The debris did not appear to strike the vehicle. No specific source for the debris was identified.

### **2.1.2 Debris near the Time of SRB Ignition**

#### **2.1.2.1 Holddown Post Debris** *(Camera E-11)*

A small piece of dark debris fell from the LSRB HDP M-7 shoe area into the SRB flame duct at liftoff.

#### **2.1.2.2 Dark Debris Falls Along Vehicle at Liftoff** *(Camera E-30)*

Several pieces of dark colored debris were seen falling with the FSS deluge water along the left side of the vehicle during liftoff. This debris did not appear to strike the vehicle.



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

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### 2.1.2.3 SRB Flame Duct Debris

*(Cameras E-5, E-7, E-8, E-9, E-11, E-12, E-14, E-15, E-16, E-25, OTV-163)*

As on previous missions, several pieces of debris were noted originating from the SRB flame duct area after SRB ignition. Two large pieces of debris (possibly closeout tags) were noted from the flame duct at liftoff (as seen on camera E-5). Three pieces of dark colored debris were seen coming out of the LSRB flame duct (as seen on camera E-11). Three pieces of dark debris, first seen near the aft skirt of the RSRB, traveled up and then fell into the SSME exhaust trench at liftoff. No damage to the SLV was observed from these events.

### 2.1.3 Debris after Liftoff

*(Cameras E-40, E-52, E-54, E-57, E-63, E-207, E-208, E-212, E-213, E-220, E-222, ET-207, OTV-161, OTV-170)*

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) between tower clear and early ascent on the launch tracking views. Most of the debris sightings were probably reaction control system (RCS) paper or ice from the ET/Orbiter umbilicals. None of the debris was observed to strike the vehicle.

### 2.1.3.1 Debris Causes Flare in SSME Plume at 31 Seconds MET

*(Cameras E-213, E-222)*

A large light colored piece of debris, first noted near the RSRB aft skirt, fell aft and flared in the SSME exhaust plume at 31.223 seconds MET.

### 2.1.3.2 Debris Seen Between 66 and 81 Seconds MET

*(Cameras E-220, E-223)*

At least seven pieces of light colored debris fell along the SRB exhaust plume between 66 and 81 seconds MET. (See Section 1.2 for UTC times).

### 2.1.3.3 Debris Reported by the Crew *(Task #10)*

CAPCOM

Atlantis, we are ready to copy a debris report when you have a moment.

ATLANTIS

Houston, on the debris report, all we are seeing is the standard ice particles that we usually see. We got just a little bit of smudging on the front windows as normal. We see nothing that is abnormal whatsoever, Joey.

CAPCOM

OK, copy that John. Thanks.

## **2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS**

---

### **2.2 MLP EVENTS**

#### **2.2.1 Orange Vapor (Possibly Free-burning Hydrogen)** *(Cameras E-19, E-20, OTV-171)*

Orange vapor (probably free burning hydrogen) was seen above the SSME #1 rim at T-5.102 seconds. This event has been noted on past missions and would become a concern if the vapor is seen as high as the umbilical areas. On this mission, however, the vapor was below the umbilicals and no follow up action was requested.

#### **2.2.2 Base Heat Shield Erosion** *(Cameras E-19, E-20)*

A small area of TPS erosion was noted on the base of the right RCS stinger during SSME ignition on camera E-19. Additional erosion was visible at the base of the left OMS nozzle on camera E-20. No follow up action was requested.

#### **2.2.3 Vapor Along Right Inboard Elevon** *(Camera E-6)*

A vapor-like substance was seen along the right inboard elevon after SSME ignition and through liftoff (2.9 seconds MET). No follow up action was requested.

### **2.3 ASCENT EVENTS**

#### **2.3.1 Body Flap Motion (Task #4)** *(Camera E-207)*

Slight body flap motion was seen as the vehicle passed through the time of maximum dynamic pressure on this mission. This event has been tracked on all missions since reflight. However, motion was not deemed sufficient to warrant more detailed analysis.

#### **2.3.2 Linear Optical Effect** *(Cameras E-207, E-208, E-212, E-223, ET-207, ET-208, ET-212, KTV-13)*

Multiple linear optical effects were seen between 70 and 80 seconds MET. Engineers at JSC have previously attributed this event seen on earlier missions to the manifestation of shock waves around the SLV. No follow-up action was requested.

#### **2.3.3 Recirculation** *(Cameras E-205, E-207)*

The recirculation or expansion of burning gases at the aft end of the SLV prior to SRB separation has been seen on nearly all previous missions. Recirculation on this mission was observed between approximately 96 and 103 seconds MET on camera E-207.

### **2.4 Onboard Photography of the ET (DTO-312)**

#### **2.4.1 Analysis of Handheld Photography of the ET (Task #6)**

DTO-312 photography of the STS-66 external tank (after separation) was acquired using a Nikon camera with a 300 mm lens and a 2X extender (Method 3). Twenty-two exposures from Magazine 01 were received. Lighting conditions at the time of the external tank photography acquisition was not good. The external tank was back lit by

## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

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the sun. After the twelfth frame, the external tank was crossing the earth's terminator and the images became very dark. The first picture was taken at 17:15:38 UTC (approximately sixteen minutes after liftoff) and the last picture was taken at 17:20:29 UTC. The focus is good on all frames. Timing data is present on the film.

In addition to DTO-312 photography, the astronauts were able to capture some video footage of the ET. Multiple pieces of white debris (probably frozen hydrogen) and vapors were visible spewing from the aft end of the external tank. The debris and vapors appeared to originate from the ET/Orbiter umbilicals. In one segment of the video the debris and vapors were seen coming from the LH2 umbilical (area). Venting from the umbilicals after separation was previously seen on STS-45, STS-53, and STS-68.

### 2.4.2 Umbilical Well Camera Analysis (*Task #5*)

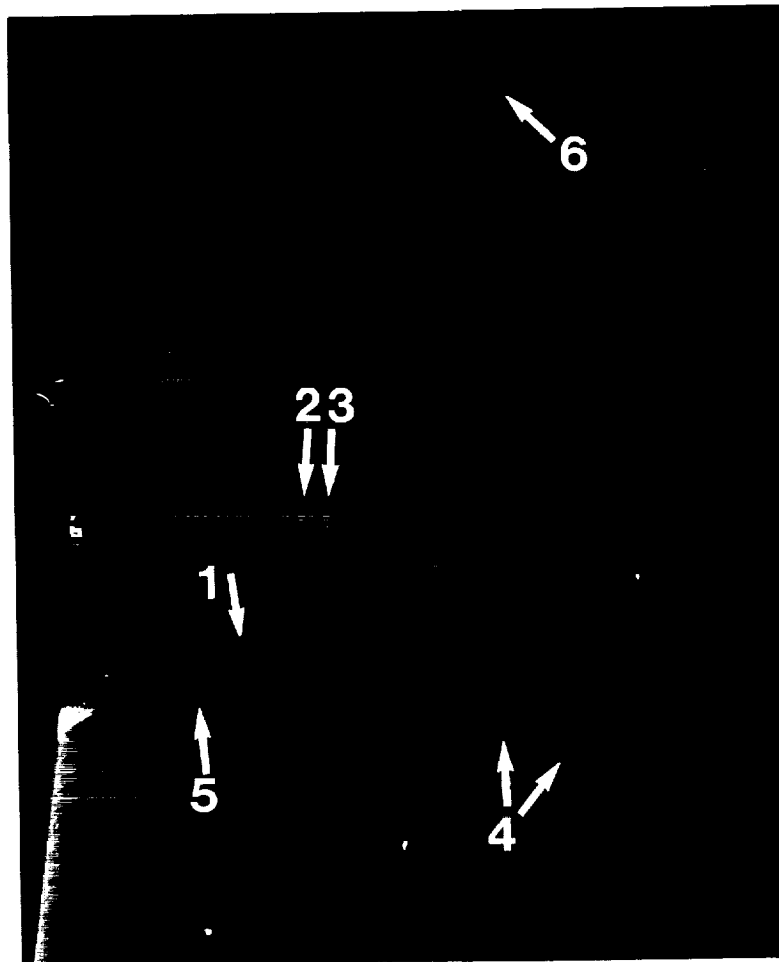
Three rolls of STS-66 umbilical well camera film were received at JSC: the 35 mm film from the LO2 umbilical and two 16 mm films (5 mm lens and 10 mm lens) from the LH2 umbilical. The +X translation maneuver was performed on STS-66. During this DTO, the ET was back lit by the sun which degraded some of the views. As a consequence, the 35 and 16 mm films had good to dark exposure. The focus was good. No timing was available on these films.



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

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### 2.4.2.1 35 mm Umbilical Film Screening



**Figure 2.4.2.1** Linear Marks on Intertank Stringer (STS066-210-058)

Sixty-one exposures of the ET were taken with the 35 mm umbilical well camera. The ET appeared in good condition but white marks (divots) and other TPS surface changes were noted. (See Figure 2.4.2.1). There was a linear shaped white divot observed on an intertank stringer forward of the ET/Orbiter forward attach bipod foot (1). A similar marks in the same position was seen on STS-62. Two additional linear shaped white marks (divots) were located on the intertank stringers forward of the forward ET/Orbiter attach near the center of the intertank. These divots measured 24 and 15 inches in length (2 and 3). Dark areas in the center of these two light colored marks indicate exposed substrate. A similar mark on an intertank stringer head was seen on the STS-58 35 mm umbilical well film. Other divots observed on the ET included:

- Two white marks (divots) on the LH2 tank/intertank closeout flange in the +Y direction from the LO2 feedline (4).
- White mark (divot) on the LH2 tank/intertank closeout flange near the left foot of the forward ET/Orbiter attach bipod (5).





## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

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- White circular shaped mark (divot) on the nose of the ET (ogive) near the LO2 pressurization line (6).

Minor TPS erosion and voids were visible on the aft LO2 feed line bellows and support bracket. The small white erosion or "pop corn" marks visible on the intertank in the vicinity of the forward ET/Orbiter attach bipod were less than that seen on most previous missions. Multiple TPS erosion marks and voids were visible on the LH2 tank TPS in the -Y direction from the aft LO2 feed line support bracket just forward of the cross beam.

The lightning contact strip at the 12' o clock position forward of the LO2 17 inch line orifice was the only structural component noted missing on the STS-66 umbilical well films. LO2 umbilical lightning contact strip(s) were also missing on STS-57, STS-58, STS-65 and other previous mission umbilical well films. The presence of the red seal around the EO-3 fitting was confirmed.

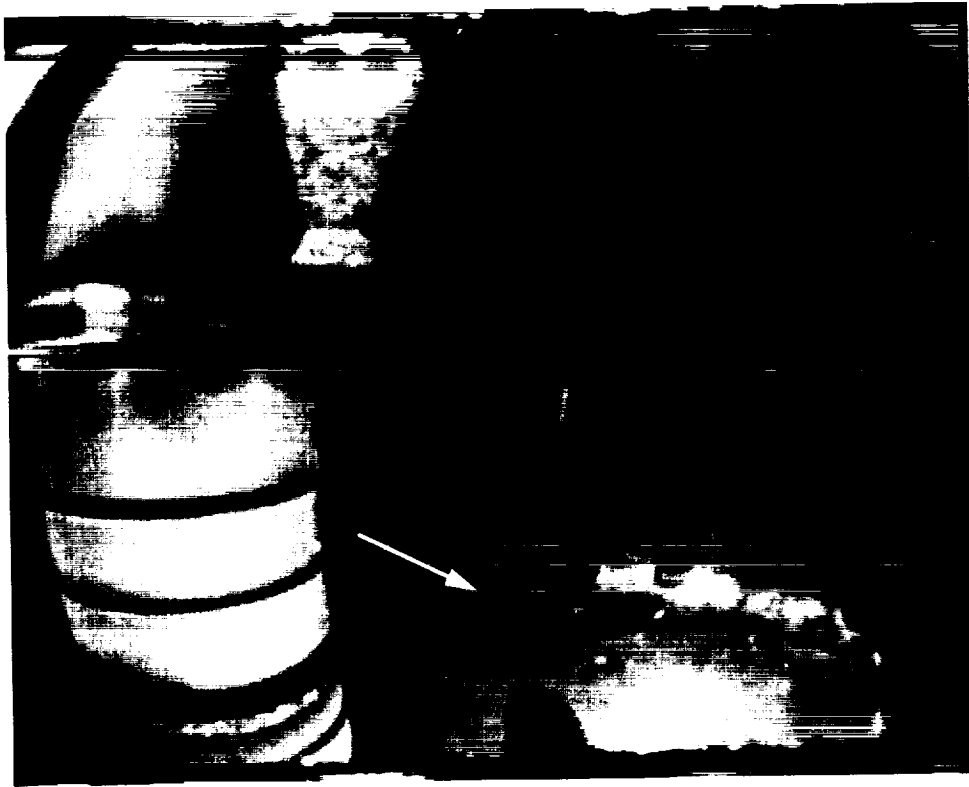
Small white debris were noted near the ET throughout the sequence of film exposures. Many of these objects appeared to be frozen hydrogen. A small bright piece of debris seen on frame 35 could not be identified.



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

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### 2.4.2.2 16 mm Umbilical Film Screening (5 mm & 10 mm Lens)



**Figure 2.4.2.2** Frozen Hydrogen at LH2 Umbilical (5mm Lens, Frame 398)

A dark, flat, rectangular shaped piece of debris was visible coming from behind the electric cable tray (on frame 398) prior to SRB separation. (See Figure 2.4.2.2). This debris may be a chip of TPS material. Similar debris from behind the electric cable tray were also visible before and after SRB separation (frames 576 and 1123 on the 5 mm lens view, frame 1197 on the 10 mm lens view). Dark debris coming from behind the electric cable tray had been seen on previous mission umbilical well camera views.

Numerous light colored pieces of debris (probably insulation) were in view throughout the SRB film sequence. Typical chipping and erosion of the electric cable tray were visible. Erosion and charring on the base of this vertical strut and of the ET/LSRB aft attach brace were visible. A blistering of the fire barrier coating on the outboard side of the LH2 umbilical was apparent. Multiple pieces of white debris (frozen hydrogen) were visible throughout the ET separation sequence. These events were typical of those seen on previous mission umbilical well camera views.

A concentrated area of white vapors was visible on the +Y side of the LSRB below the ET/LSRB aft attach (5 mm lens view, frame 735) prior to SRB separation. Similar white vapors were visible on previous mission umbilical well camera views. The vapors appeared more evident than usual on the STS-66 views (possibly due to back lighting from the sun).



## **2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS**

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A reflective linear shaped piece of debris was visible near the LO2 umbilical (10 mm view, frame 7272). This piece of debris may have been the missing lightning contact strip noted on the 35 mm umbilical film.

Frozen hydrogen was visible in the orifice of the LH2 umbilical 17 inch line connect after ET separation. Frozen hydrogen was visible aft of the cross beam forward and to the right of the LH2 umbilical (10 mm lens view, frame 6049). The red seal near the EO-2 fitting appears in place.

### **2.5 ON-ORBIT EVENTS**

There were no on-orbit events which required PTAP support. However, in response to post-flight requests from the MER and TPS engineers, analysts reviewed on-orbit videos and photography to determine whether the damage seen to the right OMS pod during the post landing walkaround was visible prior to re-entry.

#### **2.5.1 Analysis of On-Orbit Right OMS Pod Damage (Task #16)**

The icicle attached to the payload bay door may have broken loose during re-entry and caused damage to the right OMS pod and damaged the right side of the rudder. Videos and films acquired on-orbit were screened to verify that the damage was not present prior to re-entry.

All on-board Hasselblad and Linhoff films were reviewed. The best view of the right OMS pod was on Linhoff film STS66\_LINHF\_155\_160 acquired 26 hours prior to landing (94-11-13 13:35:33 UTC). No damage to the right OMS pod is visible on this view. The film quality and resolution was such, that if the damage was present it should have been visible. The rudder was imaged many times on the on-board films but the view angle from the crew cabin was not sufficient to see the right side of the rudder where the damage occurred. No definitive conclusion could be drawn about the presence or absence of rudder damage on-orbit.

Both the downlink and on-board on-orbit videos were selectively screened. None of the video views of the right OMS pod showed indications of damage. Views of the right side of the rudder were limited and provided no information on possible damage.

### **2.6 LANDING EVENTS**

#### **2.6.1 Landing Sink Rate Analysis (Task #3)**

The sink rate of the Orbiter was determined over a one-second interval prior to main gear and nose gear touchdown. The calculation method described in section 2.6.1.1 was used for all nose and main gear sink rate determinations.

## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

### 2.6.1.1 Landing Sink Rate Analysis Using Film (Cameras E-1036, E-1002)

#### STS-66 main gear sink rate (camera E-1036)

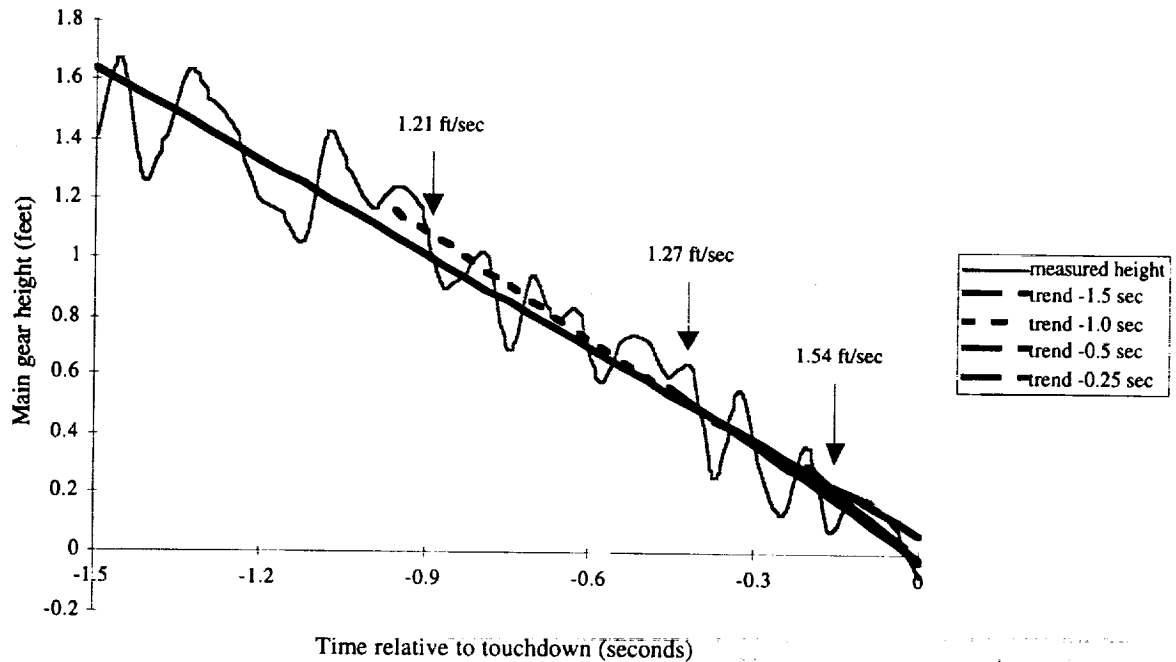
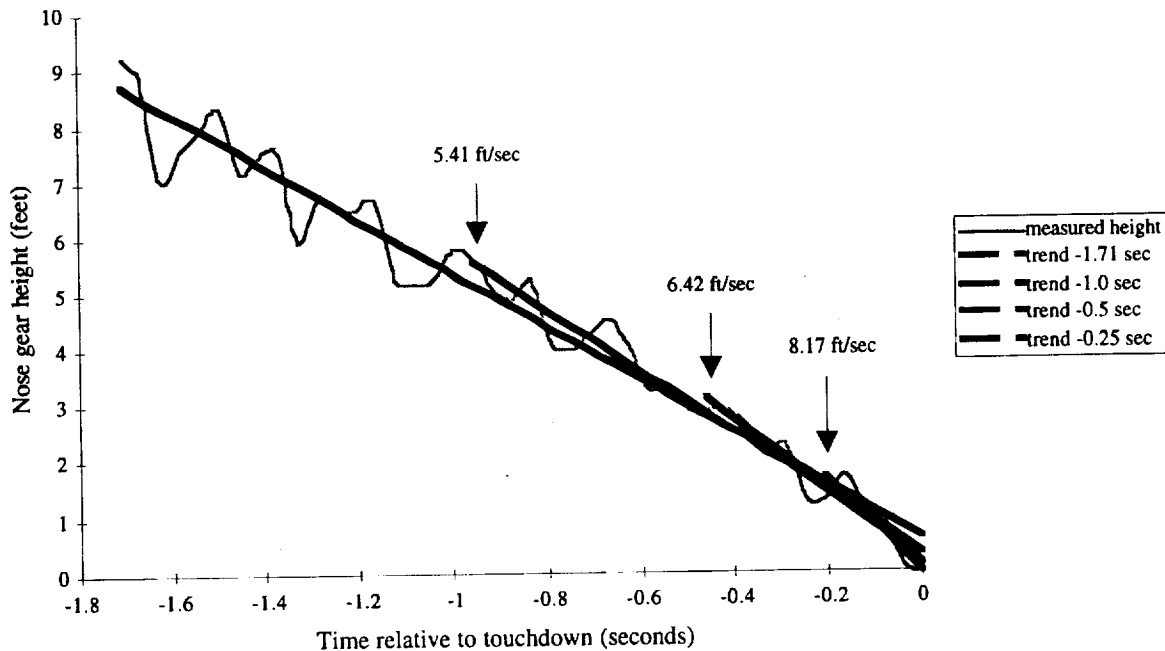


Figure 2.6.1.1(a) Main Gear Sink Rate from Film

Camera E-1036 was used to determine the landing sink rate of the main gear. The analysis considered approximately one second of imagery immediately prior to touchdown. Data was gathered at a sample rate of 24 frames per second. The diameter of the main gear was used as the scaling factor. The main gear height above the ground for each frame was calculated by multiplying the digitized height and the scaling factor. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The main gear sink rate was determined to be 1.2 feet per second. The graph of the main gear height versus time is shown on Figure 2.6.1.1(a).

## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

### STS-66 nose gear sink rate (camera E-1002)



**Figure 2.6.1.1(b) Nose Gear Sink Rate from Film**

Camera E-1002 was used to determine the landing sink rate of the nose gear. The analysis considered approximately one second of imagery immediately prior to touchdown. Data was gathered at a sample rate of 24 frames per second. The diameter of the nose gear was used as the scaling factor. The nose gear height above the ground for each frame was calculated by multiplying the digitized height and the scaling factor. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The nose gear sink rate was determined to be 5.4 feet per second. The graph of the nose gear height versus time is shown on Figure 2.6.1.1(b).

## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

### 2.6.1.2 Landing Sink Rate Analysis Using Video (Cameras TV-1, TV-3)

#### STS-66 main gear sink rate (camera TV-3)

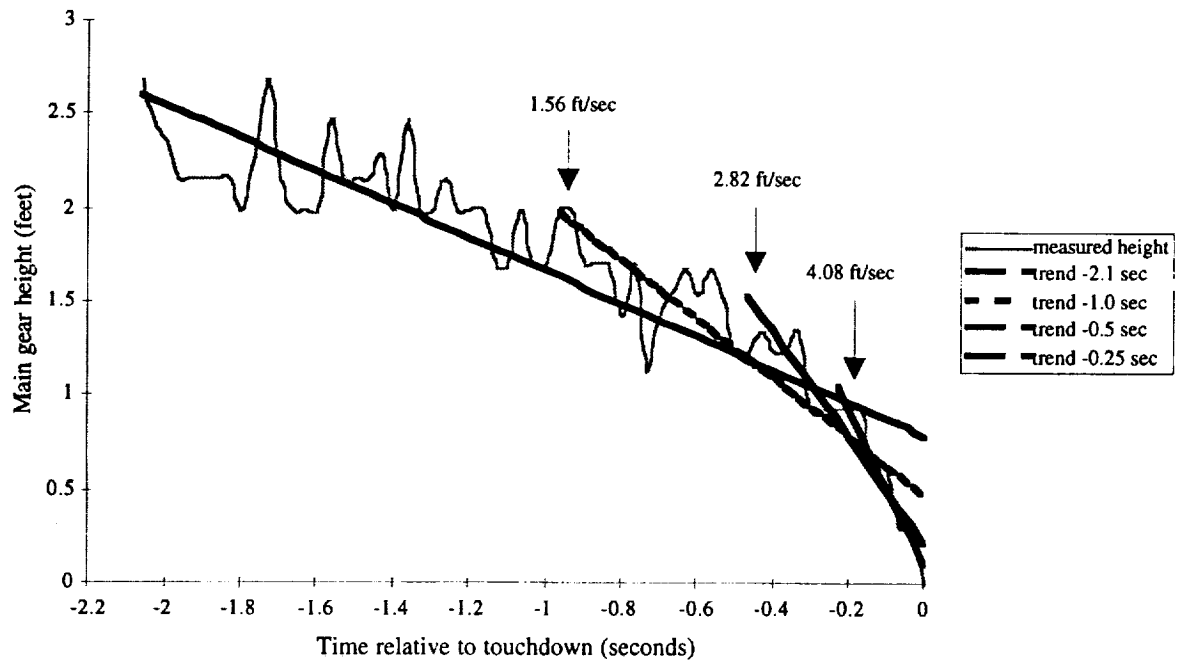


Figure 2.6.1.2(a) Main Gear Sink Rate from Video

Camera TV-3 was used to determine the landing sink rate of the main gear. The analysis considered approximately two second of imagery immediately prior to touchdown. Data was gathered at a sample rate of 30 frames per second. The diameter of the main gear was used as the scaling factor. The main gear height above the ground for each frame was calculated by multiplying the digitized height and the scaling factor. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The main gear sink rate was determined to be 1.6 feet per second. The graph of the main gear height versus time is shown on Figure 2.6.1.2(a).



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

### STS-66 nose gear sink rate (camera TV-1)

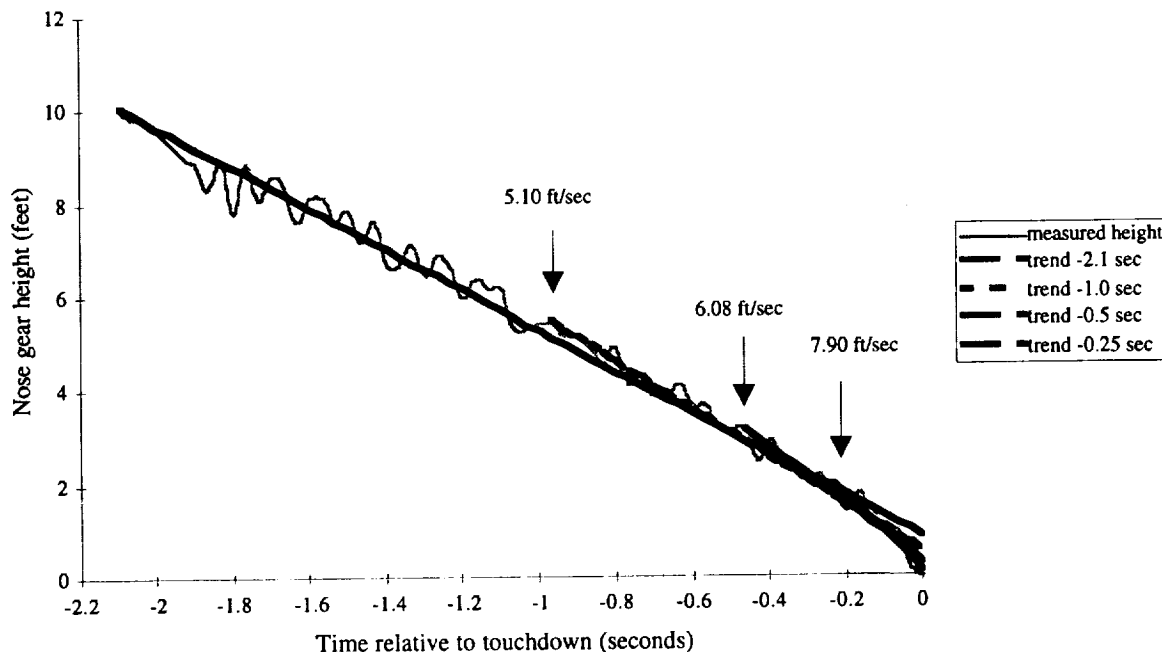


Figure 2.6.1.2(b) Nose Gear Sink Rate from Video

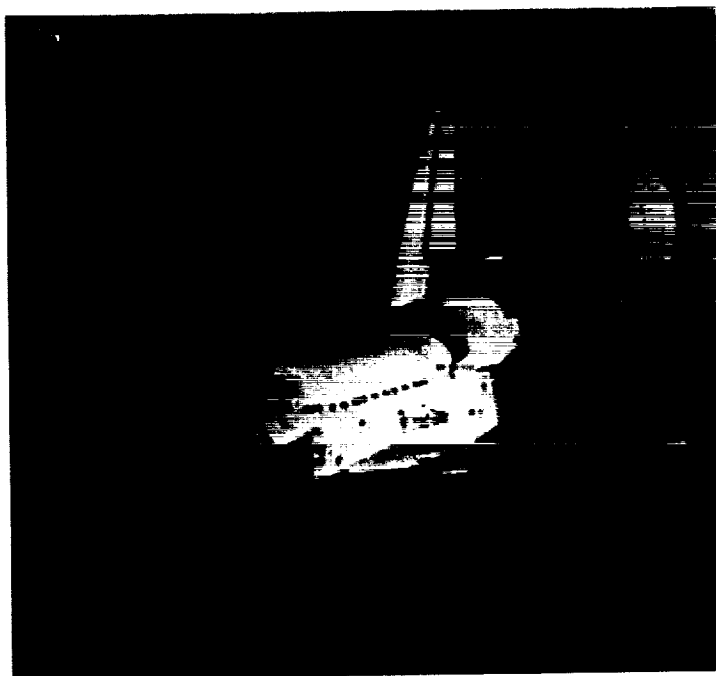
Camera TV-1 was used to determine the landing sink rate of the nose gear. The analysis considered approximately two second of imagery immediately prior to touchdown. Data was gathered at a sample rate of 30 frames per second. The diameter of the nose gear was used as the scaling factor. The nose gear height above the ground for each frame was calculated by multiplying the digitized height and the scaling factor. These heights were then regressed with respect to time. Sink rate equals the slope of this regression line. The nose gear sink rate was determined to be 5.1 feet per second. The graph of the nose gear height versus time is shown on Figure 2.6.1.2(b).

### 2.6.2 Dark Debris Seen During Drag Chute Deployment (Cameras TV-1, TV-3)

Two dark objects fell aft of the vehicle and are thought to be related to the drag chute deployment. The first dark object was first seen near the drag chute at bag release (15:33:50.803 UTC). The second object was first noted at the top edge of the drag chute and fell aft during rollout (15:34:00.646 UTC). Consultation with drag chute personnel indicates that these objects are Teflon cloth material used in packing to prevent abrasion. No further analysis of this event is expected.



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS



**Figure 2.6.2** Dark Debris Near Drag Chute

A small piece of dark debris can be seen near the 10 o'clock position of the disreefed drag chute during rollout. The debris (shown here on a camera TV-3 view) did not appear to come in contact with the vehicle.

### 2.6.3 Drag Chute Performance (*Task #9*)

The landing of Atlantis at the end of mission STS-66 marked the nineteenth deployment of the Orbiter drag chute. The deployment of the drag chute appeared as expected. Event times were obtained from cameras DTV-1 and DTV-3:

Event Description	Timing	Camera
Drag chute initiation	15:33:49.122 UTC	DTV-3
Pilot chute at full inflation	15:33:49.936 UTC	DTV-1
Bag release	15:33:50.670 UTC	DTV-1
Drag chute inflation in reefed configuration	15:33:51.704 UTC	DTV-1
Drag chute inflation in disreefed configuration	15:33:55.008 UTC	DTV-1
Chute release	15:34:16.195 UTC	DTV-1

**Table 2.6.3** Drag Chute Event Times



## 2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS

### STS-66 Drag Chute Heading Angle versus Time

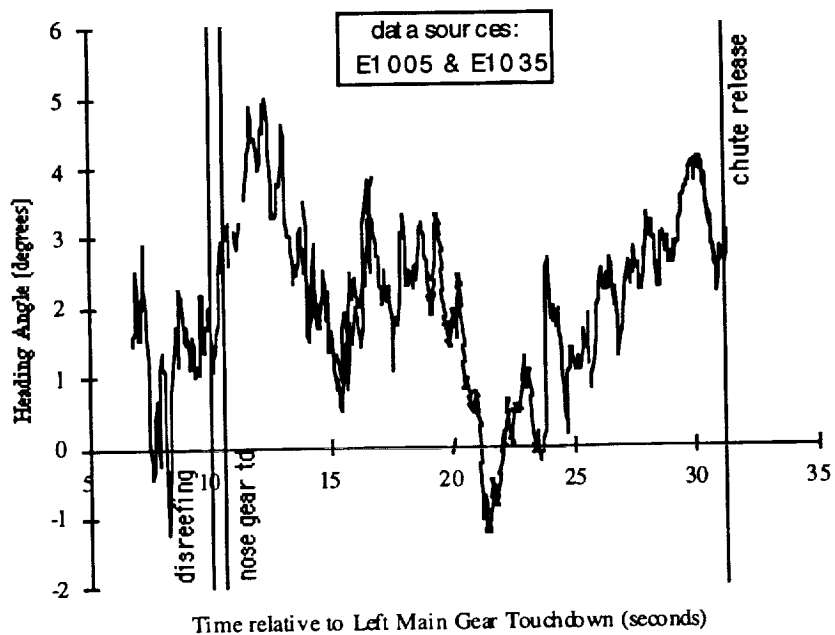


Figure 2.6.3(a) Heading Angle Versus Time

### STS-66 Drag Chute Riser Angle versus Time

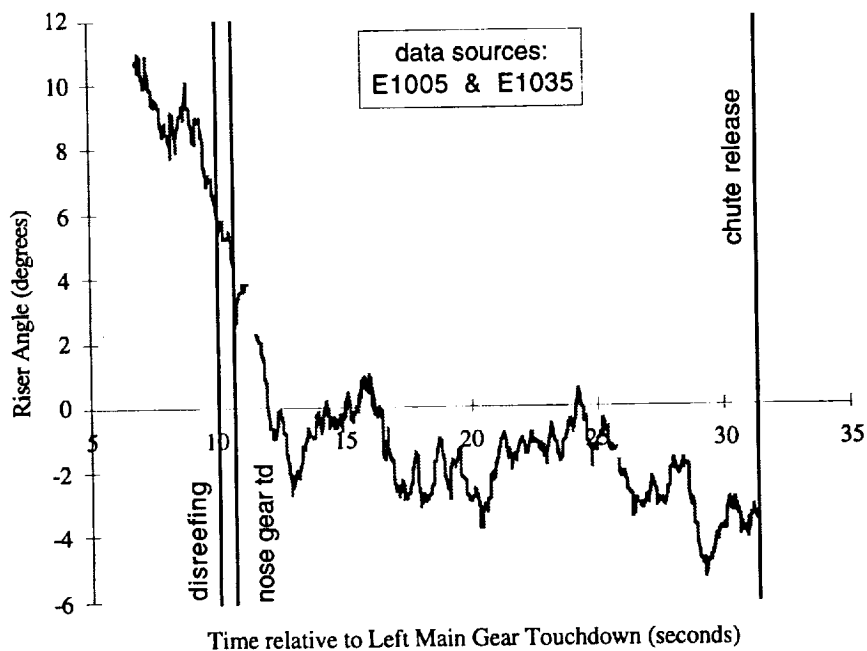


Figure 2.6.3(b) Riser Angle Versus Time

## **2. SUMMARY OF SIGNIFICANT EVENTS ANALYSIS**

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Standard analysis of the drag chute angles as a function of time was performed using the views from the video camera labeled "Runway Camera" then verified with the film cameras E-1030 and E-1031. This analysis is used to support the improvement of the aerodynamic math models currently in use. Figure 2.6.3(a) presents the measured heading angle versus time. Figure 2.6.3(b) presents the measured riser angle versus time. The maximum measured horizontal chute deflection (heading angle) was approximately 7.4 degrees to the port side of the vehicle. The vertical chute deflection (riser angle) ranged from -6.2 to +4.2 degrees relative to the Orbiter coordinate system.

### **2.6.4 Orbiter Height above Threshold (Task #13)**

The height of the Orbiter above the threshold at landing for the STS-68 mission was not completed at the time of this report. The analysis request specifies that a camera with a perpendicular view of the runway at the threshold location be used for the analysis. This view is currently only available for landings at KSC. This analysis task will be completed using alternative developmental methods as time is available.

## **2.7 OTHER NORMAL EVENTS**

Other normal events observed include: normal SSME ignition sequence, body flap vibration after SSME ignition, ET twang prior to liftoff, frost on the ET vent louvers prior to liftoff, right and left inboard and outboard elevon vibration after SSME ignition and at liftoff, RCS paper debris after SSME ignition, multiple pieces of white debris (probably ice from the ET/Orbiter umbilicals) fell along the body flap after liftoff, ice and vapor from the GUCP area during ET GH2 umbilical vent arm retraction, vapors from the ET gaseous hydrogen umbilical disconnect during early liftoff, multiple pieces of dark debris in the exhaust cloud after liftoff, acoustic waves in the SRB exhaust plume after liftoff, multiple pieces of light colored debris noted aft of the SLV during early ascent, vapor from both SRB stiffener rings after liftoff, ET aft dome outgassing, charring of the ET aft dome, flares in the SSME exhaust plume after the roll maneuver, condensation around SLV after the roll maneuver, SRB plume brightening prior to SRB separation, SRB separation, and slag in the SRB exhaust plume after SRB separation.

Normal pad events observed were hydrogen ignitor operation, fixed service structure (FSS) deluge water spray activation, sound suppression water initiation, multiple pieces of light colored debris falling from the FSS during SSME ignition, latch back of the GH2 vent arm, and MLP deluge water operation.

## **2.8 OTHER**

### **2.8.1 Terminal Events Timing Interval (Task #11)**

A detailed timeline of the SSME and SRB ignition sequences was generated and sent to R. Fletcher/JSC-VF5.

## **APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY**







National Aeronautics and  
Space Administration

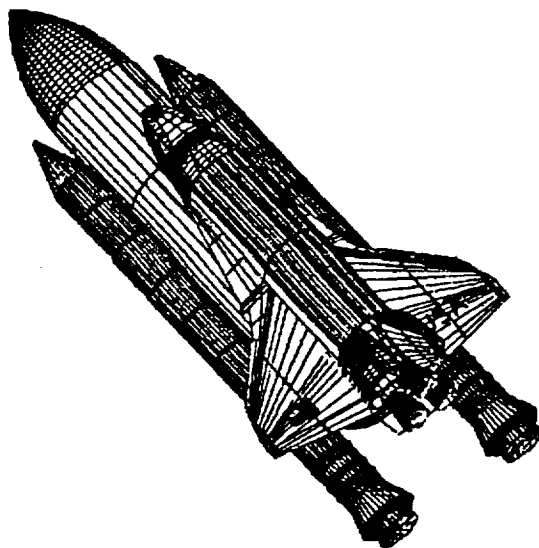
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George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35812

# SPACE SHUTTLE

## ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

### STS-66



ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT


STS-66

FINAL


PREPARED BY:

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# STS-66 ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

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  - C. SRB SEPARATION TIME

November 30, 1994

## I. INTRODUCTION

The launch of space shuttle mission STS-66, the thirteenth flight of the Orbiter Atlantis occurred on November 3, 1994, at approximately 10:59 A.M. Central Standard Time from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Extensive photographic and video coverage exists and has been evaluated to determine proper operation of the ground and flight hardware. Cameras (video and cine) providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, onboard the vehicle, and uprange and downrange tracking sites.

## II. ENGINEERING ANALYSIS OBJECTIVES:

The planned engineering photographic and video analysis objectives for STS-66 included, but were not limited to the following:

- a. Overall facility and shuttle vehicle coverage for anomaly detection
- b. Verification of cameras, lighting and timing systems
- c. Determination of SRB PIC firing time and SRB separation time
- d. Verification of Thermal Protection System (TPS) integrity
- e. Correct operation of the following:
  1. Holddown post blast covers
  2. SSME ignition
  3. LH2 and LO2 17" disconnects
  4. GH2 umbilical
  5. TSM carrier plate umbilicals
  6. Free hydrogen ignitors
  7. Vehicle clearances
  8. GH2 vent line retraction and latch back
  9. Vehicle motion
  10. External Tank TPS condition after separation (DTO-0312)

## III. CAMERA COVERAGE ASSESSMENT:

Film was received from fifty-three of fifty-four requested cameras as well as video from twenty-four of twenty-four requested cameras. The following table illustrates the camera data received at MSFC for STS-66.

**Camera data received at MSFC  
for STS-66**

	16mm	35mm	Video
MLP	21	0	4
FSS	7	0	3
Perimeter	3	3	6
Tracking	0	15	10
Onboard	2	2	1
<b>Totals</b>	<b>33</b>	<b>20</b>	<b>24</b>

**Total number of films and videos received: 77**

The individual motion picture and video camera assessments are available on the Engineering Photographic Analysis server on the World Wide Web. To view the report you will need NCSA Mosaic software. The server address is <http://photo4.msfc.nasa.gov/msfc.html>

**a. Ground Camera Coverage:**

Both film and video from ground cameras were of excellent quality. The mid-day launch time and clear skies provided good lighting conditions. However, the cameras on the MLP deck that view up (E-17, E-18, E-25, and E-26) experienced strong back-lighting from the sun. Camera E-13 which views the left SRB holddown post M-6 did not run. Timing was not recorded on camera E-16 due to a faulty timing cable.

**b. Onboard Camera Coverage:**

Twenty-two exposures of the ET after separation were recorded by the astronauts using the hand-held 35mm camera. The tank was back lighted by the sun and only the -Y axis, nose and -Z axis were visible. A video of the ET after separation was also recorded. The umbilical well cameras operated properly on this mission and provided good coverage of the SRB and ET separation events.

**IV. ANOMALIES/OBSERVATIONS:**

No anomalies were observed during the launch of STS-66.

**a. General Observations:**



While viewing the film, several events were noted which occur on most missions. These included: pad debris rising and falling as the vehicle lifts off, debris induced streaks in the SSME plume, ice falling from the 17 inch disconnects and umbilicals, and debris particles falling aft of the vehicle during ascent, which consist of RCS motor covers, hydrogen fire detection paper and purge barrier material, loose SRB thermal curtain tape, glowing debris particles exiting the SRM plumes and slag from the SRM's prior to and during SRB separation.

Three streaks of similar appearance and position were observed from the ME-1 nozzle prior to liftoff. These streaks occurred at 16:59:41.877, 16:59:41.885, and 16:59:41.912 UTC as recorded by camera E-3. Figure 1 depicts the third occurrence of this event.



Figure 1 Streak in ME-1 at 16:59:41.912 UTC

A piece of orbiter TPS tile was observed falling between the body flap and the ME-2 nozzle during SSME ignition at 16:59:40.2 UTC. The origin of the tile could not be determined. The tile appears to be approximately 1 x 2 x 6 inches in size and to be a broken piece. Figure 2 is a film frame from camera E-18 showing this tile piece.

A debris particle was observed between the SRB's, aft of the ET aft dome, and became entrained in the SSME plume creating





a large flare in the plumes at T+25.07 seconds. This event was recorded by camera E-213 and is shown in Figure 3 and Figure 4.

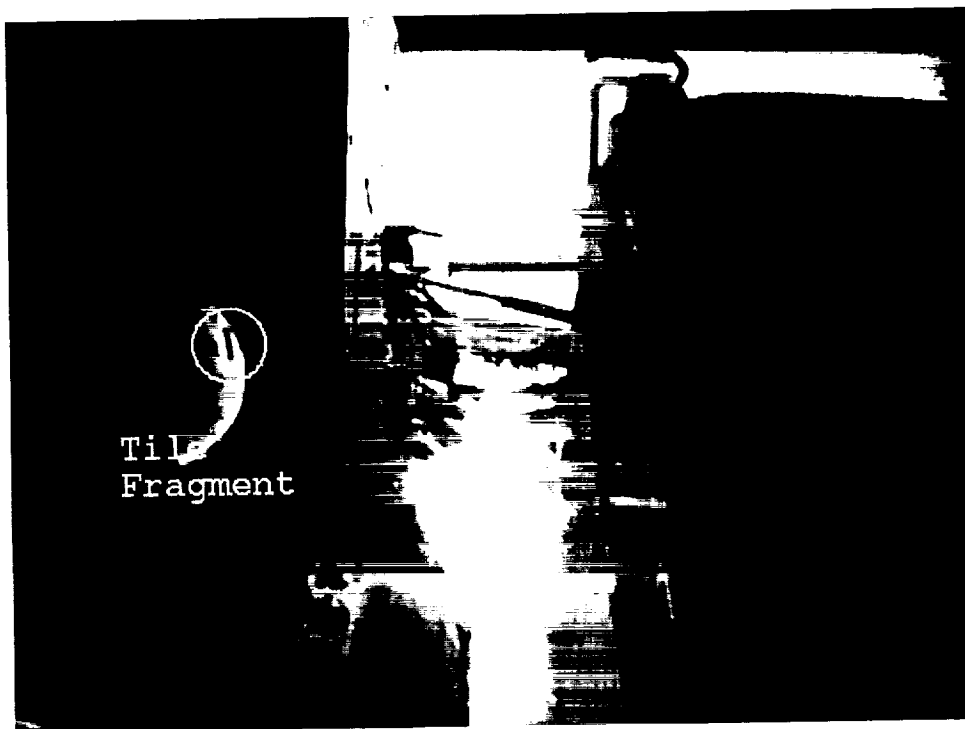


Figure 2 Broken tile piece falling from vehicle

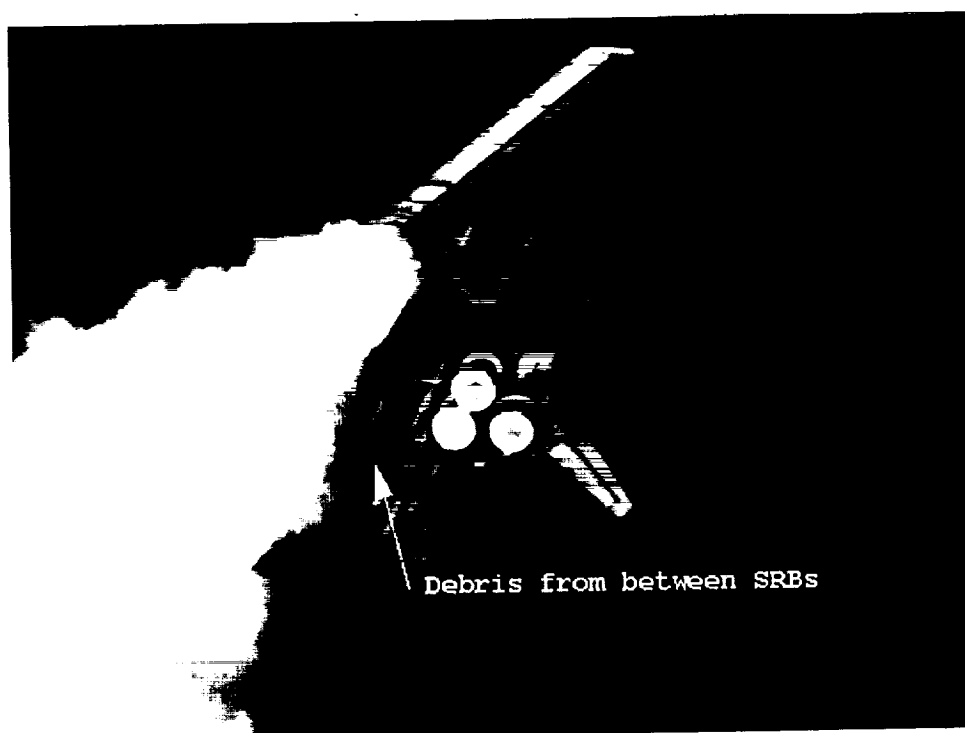


Figure 3 Debris particle between SRB's



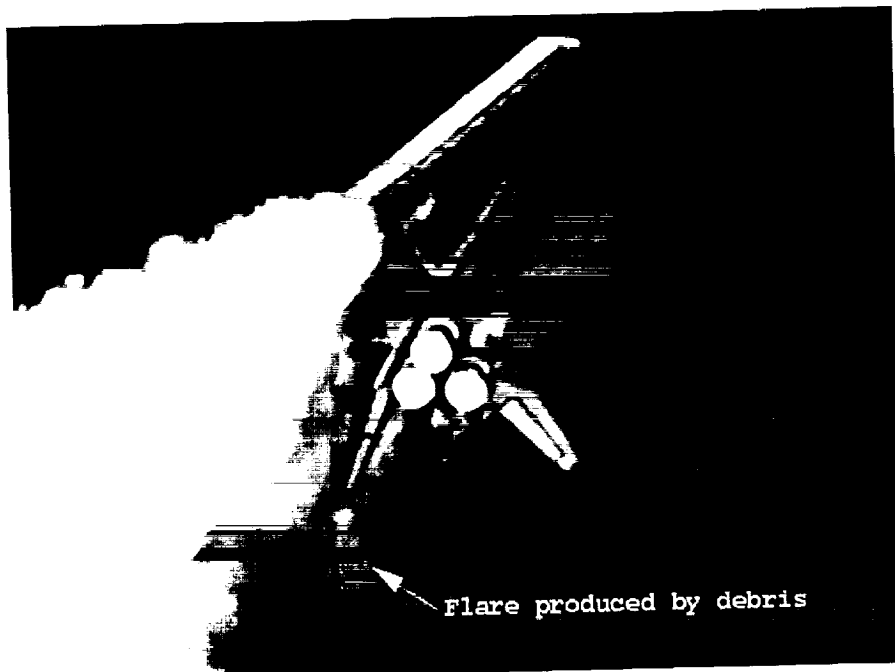


Figure 4 Debris particle in SSME plume

A rope like debris particle was observed falling from near the left SRB nozzle exit plane at T+66.72 seconds. Figure 5 is a film frame from camera E-212 showing this event. Previous debris of this type has been attributed to either SRM plume particles or thermal curtain tape.

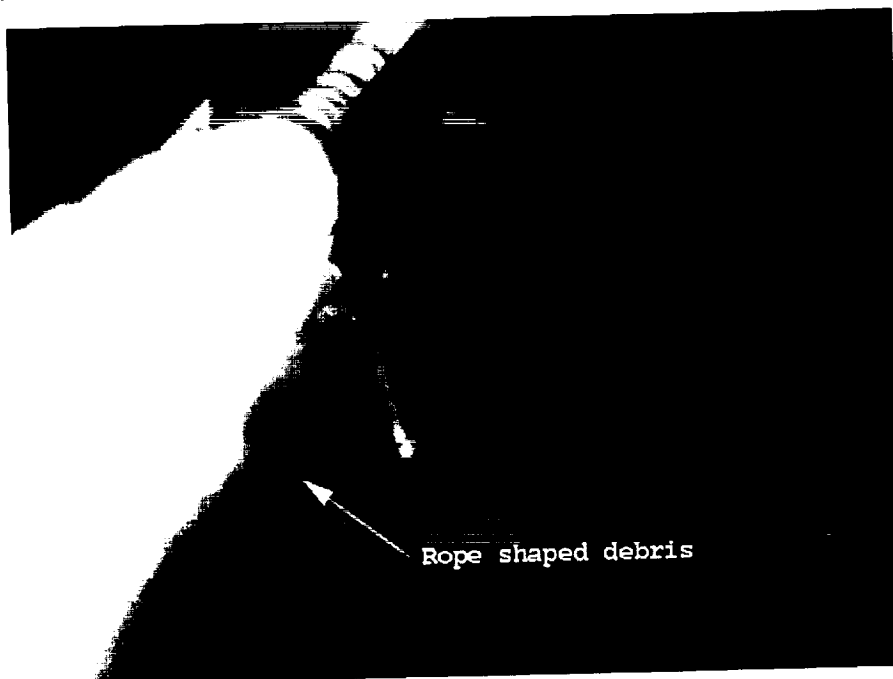


Figure 5 Debris particle falling from near left SRB nozzle



b. ET TPS assessment:

Several divots were noted on the ET from the umbilical well cameras after separation. Popcorning of the lower third of the LH2 tank TPS acreage was noted as shown in Figure 6.

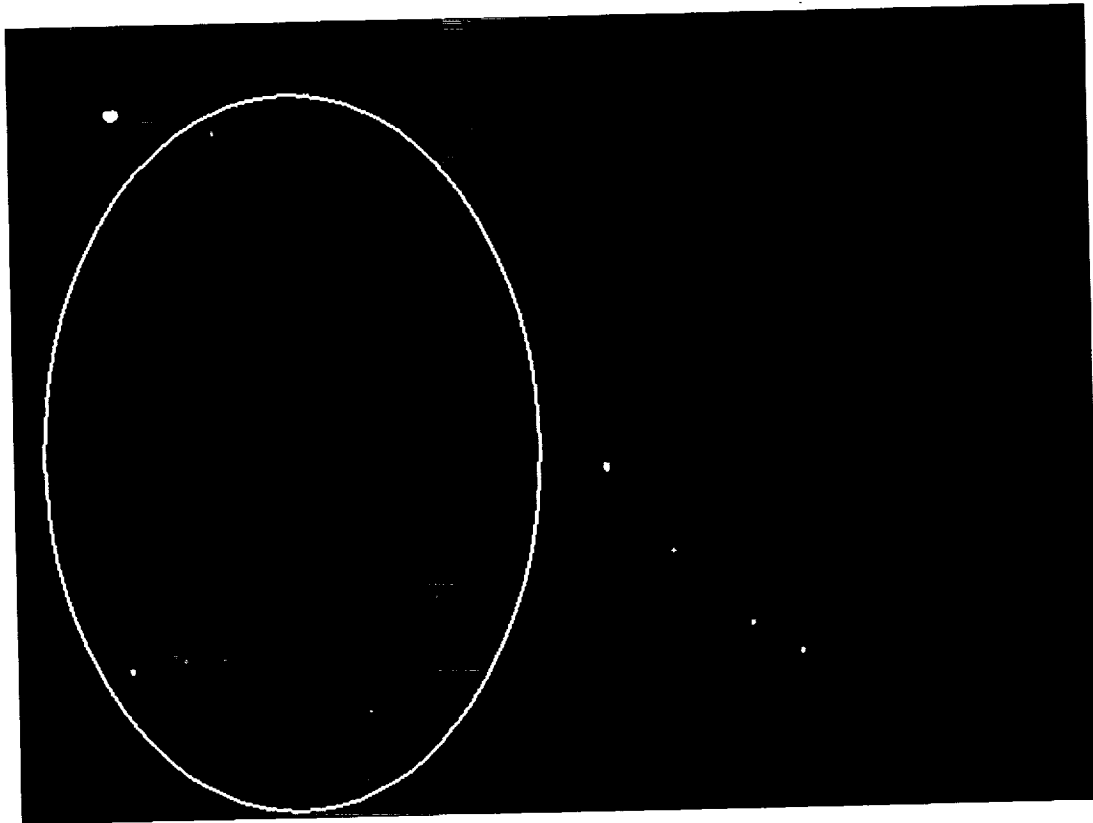


Figure 6 Popcorning of LH2 tank TPS acreage

Two large divots were noted on the intertank aligned with the stringers along the +Z axis. These divots appear to be 4 x 36 and 4 x 24 inches in size, respectively. Several divots were noted on or near the intertank/LH2 tank scarf joint. A divot was located on the leading edge of the left bipod ramp. A divot was located on the GOX pressurant line ramp midway along the ogive. These divots are shown in Figure 7 which was taken from the 35mm camera located in the orbiter LO2 umbilical well.



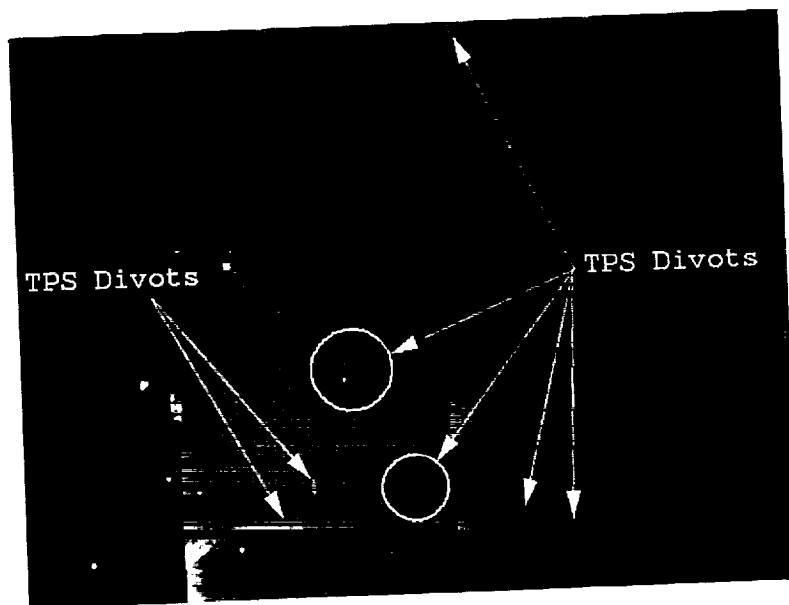


Figure 7 ET TPS divots

c. ET venting:

Venting of gases and solid particles after separation was observed on the handheld camcorder video recorded by the astronauts. The venting was occurring from both the LH2 and LO2 17 inch disconnects. No timing information is available. However, approximately 2 minutes of the venting was recorded and was continuing at the end of this tape. This venting is shown as Figure 8.

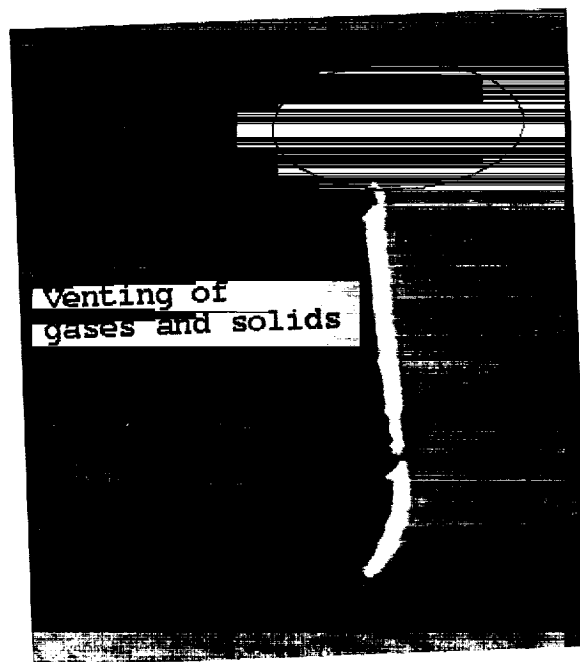


Figure 8 ET venting





## V. ENGINEERING DATA RESULTS:

### a. T-Zero Times:

T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5 and M-6. These cameras record the explosive bolt combustion products.

HOLDDOWN POST	CAMERA POSITION	TIME (UTC)
M-1	E-9	16:59:43.012
M-2	E-8	16:59:43.014
M-5	E-12	16:59:43.012
M-6	E-13	No run

### b. ET Tip Deflection:

Maximum ET tip deflection for this mission was determined to be approximately 31 inches. Figure 9 is a data plot showing the measured motion of the ET tip in both the horizontal and vertical directions. A positive horizontal displacement represents motion in the -Z direction. These data were derived from film camera E-79.

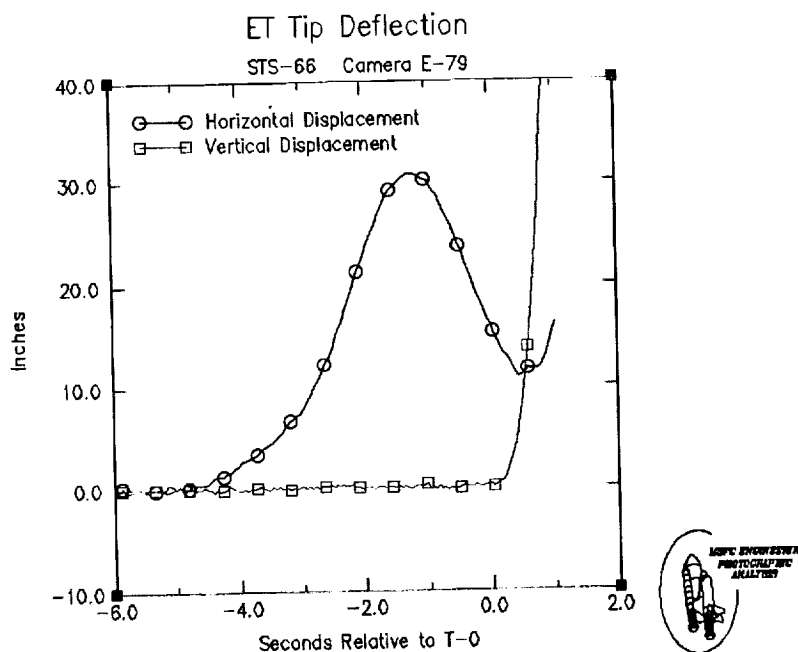


Figure 9 ET Tip Deflection

### c. SRB Separation Time:

SRB separation time for STS-66 was determined to be 307:17:01:47.72 UTC (124.72 seconds MET) as recorded by camera E-208.



# REPORT DOCUMENTATION PAGE

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